

Original Article

# Use of the Novel Derivatizing Agent 1,8-Diaminonaphthalene With the CIP10 Sampler to Measure 4,4'-Methylene Diphenyl Diisocyanate Atmospheres

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## Abstract

DAN is a novel derivatizing agent for isocyanate sampling which targets total reactive isocyanate group (TRIG). Field evaluations have been conducted for 4,4'-Methylene diphenyl diisocyanate (MDI) sampling using DAN as the derivatizing agent in a CIP10. The perimidone formed, selective of TRIG, was analyzed in laboratory by liquid chromatography coupled to tandem mass spectrometry. Workplaces using MDI-based polyurethane spray foam and MDI wood product binder were studied. Each study compared the data obtained between the CIP10/DAN, the CIP10/MP, and a reference method. As a first evaluation, the CIP10/DAN sampled simulated MDI spray foam atmosphere in parallel with impingers (reference method) and CIP10/MP. The mean of the TRIG concentration values measured was 16% (95% confidence interval [CI], [1, 31]) higher for the CIP10/MP samples as compared to the impinger samples, while the mean TRIG concentrations found were 98% (95% CI [63, 133]) higher for the CIP10/DAN samples as compared to the impinger samples. For sampling done in a real workplace using MDI-based spray foam, the CIP10/DAN method showed lower results than the CIP10/MP method. The presence of hygroscopic DMSO used in the DAN approach is a limitation and may prevent obtaining accurate results in the spray foam atmosphere. CIP10/DAN was also studied in MDI wood product binder atmosphere. Mean TRIG concentrations found were 80% (95% CI [51, 110]) and 79% (95% CI [50, 108]) lower for the CIP10/MP and CIP10/DAN method, respectively, as compared to the reference method (a 13-mm filter coated with MP). In this case, the CIP10 may have reached its limit in this last evaluation

where vapors and particles below 1  $\mu\text{m}$  were not collected as efficiently as they were with the reference method.

**Keywords:** 1,8-diaminonaphthalene; exposure assessment methodology; isocyanate; methylene diphenyl diisocyanate; perimidone

## Introduction

4,4'-Methylene diphenyl diisocyanate (MDI) is an isocyanate used in the production of polyurethane products such as insulation foam and wood product binder. MDI is known to cause occupational illnesses such as occupational asthma and cutaneous and respiratory irritation (Malo *et al.*, 1983; Banks *et al.*, 1986; Mapp *et al.*, 1988; Musk *et al.*, 1988; Vandenplas *et al.*, 1992; Vandenplas *et al.*, 1993; Mapp *et al.*, 1999). Many countries have set an occupational exposure limit (OEL) of 5 ppb for the monomer in order to control exposure to this chemical substance (Occupational Safety & Health Administration 1992; National Institute for Occupational Safety and Health 1996; Swedish National Board of Occupational Safety and Health 2000; American Conference on Government Industrial Hygienists 2014; Quebec (Province) 2014). In a prevention context, however, it is best to monitor and control all forms of isocyanates, i.e. monomer and oligomers, in order to best protect workers' health and avoid occupational diseases (Bello *et al.*, 2004). In addition, countries such as Australia, Finland, Ireland, and the UK have set OELs for total reactive isocyanate group (TRIG) rather than for the monomeric species alone (Allport *et al.*, 2003; Health and Safety Laboratory 2014). These OELs require a different way of treating the sampling data linking the individual sampled substances, monomeric, and oligomeric, to TRIG.

The sampling of isocyanates must be efficient for vapors and aerosols as both physical forms can be present in workplaces. Also, isocyanate monitoring is generally conducted in two phases. First, the isocyanate is stabilized in the field using a derivatizing agent in a sampling device. Subsequently, the derivative is analyzed in laboratory using liquid chromatographic techniques. One approach used by most currently available methods is the conversion of the reactive isocyanate in a stable urea (Streicher *et al.*, 1998; Marand *et al.*, 2005; Nordqvist *et al.*, 2005; Lesage *et al.*, 2007; Gylestam *et al.*, 2014b; Puscasu *et al.*, 2015a). The urea formed is selective of the monomeric species or the oligomeric species. Recently, an alternative approach has been reported for the analysis of a derivative selective for TRIG (Streicher *et al.*, 2006; Bello *et al.*, 2013). This approach uses 1,8-diaminonaphthalene (DAN) as the derivatizing agent. The DAN reagent reacts with the isocyanate in the

sampler to form a urea. During subsequent laboratory workup, a cyclization occurs to form a single analyte, perimidone, corresponding to each NCO group with which DAN reacted. Puscasu *et al.* (2016) have recently evaluated independently the work of Bello and Streicher on the fundamentals of the DAN method (Bello *et al.*, 2002; Bello and Woskie 2005; Bello and Streicher 2013), including sample collection and workup protocols and the liquid chromatography coupled with tandem mass spectrometry (LC-MS/MS) analysis. This analytical method showed reliability in the laboratory and the approach has the potential to analyze the presence of the totality of the isocyanates without targeting individual isocyanate species. It appears to be a tool of choice for assessing TRIG and prevention contexts where all isocyanate forms must be monitored, and complements the species-specific information provided by conventional isocyanate derivatization methods.

Besides the derivatizing agent, the type of sampling device must be chosen for efficient sampling and derivatization of all forms of the airborne isocyanate (i.e. vapor and aerosol). Impingers are known to have limitations linked to solvent flammability and evaporation as well as fragility of the sampler (Streicher *et al.*, 1998; Lesage *et al.*, 2007; Puscasu *et al.*, 2015a). Filter approaches are reported to underestimate the amount of MDI sampled in spray foam compared to impingers (Streicher *et al.*, 1998; Lesage *et al.*, 2007). The ASSET EZ4-NCO is also known to underestimate MDI levels in spray foam compared to impingers (Puscasu *et al.*, 2015b). One sampling device which has shown promising results for MDI aerosol sampling is the CIP10 (Puscasu *et al.*, 2015a). The CIP10 showed MDI levels in the same range as the impingers for the sampling of MDI in spray foam where aerosols were mainly present (Roberge *et al.*, 2009; Puscasu *et al.*, 2015a). The objective of this study is to introduce the DAN reagent in a CIP10 for the sampling of MDI in two different applications representative of MDI usages. Workplace evaluations will be conducted in a foam spraying environment where MDI and polyol are present and in a wood binder environment where polyol is not present (MDI alone) to establish potential artefacts with DAN in the presence of polyol. Comparisons between the DAN approach and a reference method will be presented for each application.

## Materials and methods

### Chemicals

4,4'-MDI (98% purity), MP (98% purity), dimethyl sulfoxide (DMSO; >99.9%), tributylphosphate (TBP; >99%), acetone (HPLC grade), formic acid (>95% purity), ammonium acetate (>99%), and acetic anhydride (98% purity) were obtained from Sigma-Aldrich (Milwaukee, USA) and were used without any further purification. 1-Propanol (>99%) was obtained from EMD Chemicals Inc. (Gibbstown, NJ). DAN (99% purity), 1H-perimidin-2(3H)-one (perimidone, 99% purity), and d6-perimidone (99% purity) were obtained from Nuchem Therapeutics (Montréal, Canada). Acetonitrile (ACN), water (H<sub>2</sub>O), methanol (MeOH), formic acid (FA), all optima LC-MS grade, and sodium acetate (99.4% purity) were obtained from Fisher Scientific (St-Laurent, QC, Canada). Glacial acetic acid (96% purity) was obtained from J.T. Baker. Toluene (99.9% purity) was obtained from EMD Millipore Corp. (Billerica, MA, USA). The in-house synthesis of MDI-MP monomer derivative and the purity check were done using a known and reliable procedure (Puscasu *et al.*, 2015a).

### Instruments and analytical conditions

The impinger and the CIP10/MP samples were analyzed with the same instrument and conditions as described previously (Puscasu *et al.*, 2015a). The MP-coated 13-mm filter method was used in conditions equivalent to what is reported (Huntsman Polyurethanes 2003). The perimidone samples from the CIP10/DAN were analyzed as previously reported (Puscasu *et al.*, 2016).

### Sample and standard preparation

The impinger and CIP10/MP samples and standards were prepared using a previously described protocol (Puscasu *et al.*, 2015a). The MP-coated 13-mm filter samples and standards were prepared in conditions equivalent to what is reported (Huntsman Polyurethanes 2003). The perimidone standards were prepared as previously described (Puscasu *et al.*, 2016). The CIP10/DAN samples were prepared as follows: 1.5 to 2 ml of DMSO with 50 mM of DAN was used in the CIP10. Post-sampling volume was established using a graduated syringe; 0.5 ml was filtered and transferred to a LC vial. Ten  $\mu$ l of internal standard d6-perimidone 10  $\mu$ g/ml in methanol was spiked in the aliquot for a final concentration of 100 ng/ml; 0.48 ml of FA was added to the LC vial and mixed. After 30 minutes, 10  $\mu$ l of acetone was spiked in the LC vial and mixed. The final volume of the solution is 1 ml. The residual solution is injected by UPLC-MS/MS.

### Air sample collection

Impinger and CIP10/MP samples were collected as previously described (Puscasu *et al.*, 2015a). CIP10/DAN samples were collected at 10 l/min with 2 ml of solution in the CIP10. The simulated workplace set-up using the 'sample homogenizer jar' was similar to the one previously described (Puscasu *et al.*, 2015a). The sprayer worked in a 4.4  $\times$  4.7  $\times$  2.3 m room with the ceiling and walls covered by a vinyl curtain. Three plywood panels (1.2  $\times$  2.4 m) were placed in the room and the sprayer applied 2 cm of foam on each plywood panel every 5 minutes, using a procedure similar to that used in a normal working day. The products sprayed were Airmétic Soya<sup>MD</sup> Isocyanate A100 (CAS #9016-87-9, 101-68-8) manufactured by Demilec Inc. during day 1 and Waminate PM-200 (CAS #9016-87-9, 101-68-8), manufactured by Wanhua Chemical Group Co during day 2. The products contained at least 30% MDI monomer (%Wt) with the remainder being oligomeric isocyanate species based on their material safety data sheets. Inside the room, the sampling jar containing three impingers with MP (reference method), three CIP10 with MP, and three CIP10 with DAN was positioned near the sprayer. After each application, the sprayer was asked to leave the room. Each test consisted of this procedure repeated three to six times, depending on the test, which led to test durations of ~30 minutes. A total of six tests were carried out over two days of sampling for a total of 54 samples ( $n = 3$  for each test).

The real polyurethane spray foam workplace environments were as follows. The first house was in construction. The polyurethane spray foam was applied mainly in the basement and in few spots on the first floor by a professional sprayer and his helper. The product sprayed was Airmétic Soya<sup>MD</sup> Isocyanate A100 (CAS #9016-87-9, 101-68-8) manufactured by Demilec Inc. A total of 89 m<sup>2</sup> of polyurethane spray foam was applied by the two workers. Each worker wore two CIP10 in the personal breathing zone. The first was CIP10/MP (reference method) and the second was CIP10/DAN. A post was located one to three meters away from the sprayer in the basement. Two CIP10/MP (reference method) and two CIP10/DAN were located on this post in order to collect ambient (area) samples. CIP10/MP samples were collected as previously described (Puscasu *et al.*, 2015a). CIP10/DAN samples were collected at 10 l/min with 1.5 ml of 50 mM DAN in the sampling solution in the CIP10. Samples were collected for 30 minutes. Two sample collection series were performed.

The second house was in renovation. The polyurethane spray foam was applied in the basement by a professional sprayer alone and a helper was simulated

in the area. The product sprayed was Airmétic Soya<sup>MD</sup> Isocyanate A100 (CAS #9016-87-9, 101-68-8) manufactured by Demilec Inc. A total of 78 m<sup>2</sup> of polyurethane spray foam was applied by the sprayer. Personal breathing zone and ambient samples were collected as in the first house. Samples were collected for 30 minutes and three sample collection series were performed.

The wood product binder environment was as follows. The samplers were located near the forming line during normal operation with phenolic resin powder and pMDI Rubinate® 1840 used as the wood product binder. In this process, the isocyanates are aerosolized into two forms: bound to wood particles (monomer and oligomers) and, to a lesser extent, in vapor (monomer only). The MP-coated 13-mm filter sample cassettes (reference method) were composed of 13-mm glass fiber filters precoated with MP assembled in Swinex cassettes and were supplied by Bureau Veritas North America, Inc. (Detroit, MI). Three 13-mm filter cassettes (reference method), three CIP10/MP, and three CIP10/DAN were placed side by side. Samples were collected for 60 to 90 minutes as done previously and four series were performed. Particle-size distribution was measured using a cascade impactor as previously described (Puscasu *et al.*, 2015a).

### TRIG calculation

From MP sampling for monomeric species:

$$\text{TRIG (mg / m}^3\text{)} = \left( \text{MDI mass (mg / sample)} \times \left( \frac{2 \times \text{molecular weight NCO}}{\text{molecular weight MDI}} \right) \right) / \text{air volume (m}^3\text{)}$$

$$\text{TRIG (mg / m}^3\text{)} = \left( \frac{\text{MDI mass (mg / sample)}}{\times (2 \times 42 / 250)} \right) / \text{air volume (m}^3\text{)}$$

$$\text{TRIG (mg / m}^3\text{)} = \text{MDI concentration (mg / m}^3\text{)} \times 0.336$$

Results for the non-monomeric species would be reported as the total peak area detected and quantified using the standard curve prepared with the MDI-MP monomer, since no individual pure MDI-MP non-monomeric standards are available. This is based on the well-established assumption of an equimolar detector response of the MDI-MP. Therefore, correcting the non-monomeric response for the percentage of NCO function in the monomer (as shown in the equation above) allowed TRIG calculation for any oligomeric species.

From DAN sampling:

$$\text{TRIG (mg / m}^3\text{)} = \left( \text{perimidone mass (mg / sample)} \times \left( \frac{\text{molecular weight NCO}}{\text{molecular weight perimidone}} \right) \right) / \text{air volume (m}^3\text{)}$$

$$\text{TRIG (mg / m}^3\text{)} = (\text{perimidone mass (mg / sample)} \times (42 / 184)) / \text{air volume (m}^3\text{)}$$

$$\text{TRIG (mg / m}^3\text{)} = \text{perimidone concentration (mg / m}^3\text{)} \times 0.228$$

TRIG concentrations were compared between the reference method, the CIP10/MP and CIP10/DAN

sampling methods in a total of four to six different tests. Descriptive statistics (histograms, normal probability plots) were applied to determine TRIG data distributions. Since preliminary investigation indicated a within-test correlation between TRIG, analyses were carried out using linear mixed effect models assuming a hierarchical structure of the data, with the TRIG results as the dependent variable. The TRIG sampling method (reference method; CIP10/MP, CIP10/DAN) was included in the models as a fixed effect, and the test number as a random effect. TRIG concentrations were not log transformed because the TRIG distributions were approximately normal. The following model was fitted to the data:

$$C_{ij} = \alpha + \beta * \text{method}_{ij} + a_i + \epsilon_{ij}$$

TRIG concentrations ( $C_{ij}$ ) in mg/m<sup>3</sup> were modeled as an intercept ( $\alpha$ ), plus a sampling method effect ( $\text{method}_{ij}$ ), a random intercept  $a_i$  that is assumed to be normally distributed with mean 0 and variance  $\sigma_a^2$ , and residual error ( $\epsilon_{ij}$ ). The index  $i$  refers to tests ( $i = 1, \dots, 6$ ) and  $j$  to the observation within a test ( $j = 1, \dots, 9$ ). The term  $\epsilon_{ij}$  is the within-test variation and is assumed to be independently normally distributed with mean 0 and variance  $\sigma^2$ . The plot of residuals against fitted values showed some evidence of heterogeneity because the residual spreads were different between the three MDI sampling methods. The random structure was optimized by adding a different residual standard deviation for each level of the method variable.

All analyses were performed using R 3.1.3 statistical software (R Development Core Team, Vienna, Austria).

## Results and Discussion

### Laboratory performances

Prior to field evaluations, each derivatization medium is tested for recovery of a known spiked concentration in addition to the analytical performances reported in the literature. This additional test is done to be sure that the sampling material has been prepared properly. The recoveries are established using solutions of free MDI monomer spiked in the mediums. The target concentrations are determined using a pure source of MDI monomer and the true concentrations are based on mass concentration of stock solutions. All concentration levels are contained in the dynamic range of each method. Each recovery obtained is presented in Table 1. As seen in this table, the recovery is close to 100% for all the methods used except the CIP10/DAN method, where the recovery is slightly lower than 90%. However, all recoveries were judged adequate to conduct the field evaluations.

### Field comparison with the sample homogenizer jar

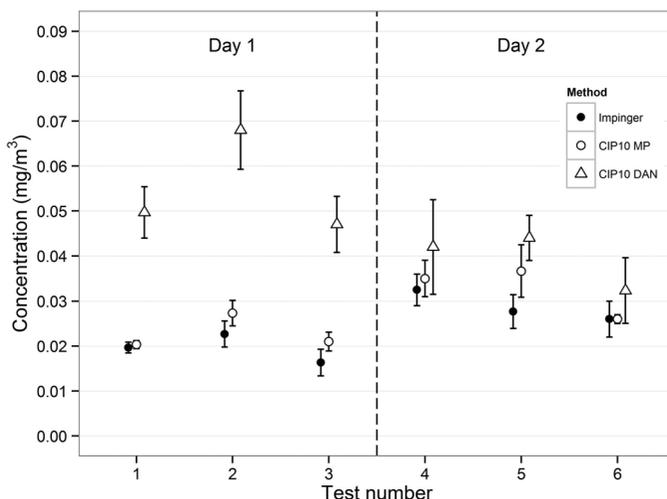
The tests were conducted over two different days in order to obtain a sufficient number of samples to achieve statistical method reliability with a high level of confidence without overburdening the workers. The mass median aerodynamic diameter (MMAD) measured by our group inside the jar was 13  $\mu\text{m}$  with a GSD of 7. The two datasets are presented in Fig. 1. As can be seen in Fig. 1, mean TRIG concentrations were 16% (95% confidence interval [CI], [1, 31]) higher for the CIP10/MP sampler as compared to the impinger sampler. The results obtained with the CIP10/MP are judged to be in the same range as those obtained with the impinger in a previous study (Puscasu *et al.*, 2015a). A bias of 16% is considered very low compared to the typical environmental variability observed in workplace exposure data. In addition, mean TRIG concentrations determined with the CIP10/DAN sampler were 98% (95% CI [63, 133]) higher for the method as compared to the impinger sample results and cannot be explained by the collection efficiency alone. These higher results may be explained by the fact that the analytical method used for the impinger and CIP10/MP samples provides TRIG concentration

based on the MDI monomer and some small oligomers only. The CIP10/DAN analytical method provides TRIG concentration based on total amount of isocyanate function, which is likely much more abundant than the isocyanate functions of the monomer and the smaller oligomers only in a reacting system such as spray foam insulation. Large oligomers and partially reacted isocyanate function from the polymer also react with the DAN, leading to perimidone formation and higher TRIG concentration.

A closer look at Fig. 1 also reveals a different trend for the CIP10/DAN method when day 1 is compared to day 2. The difference with the impinger method is less significant when day 2 is taken alone. This difference may be explained by a CIP10 limitation when operated with DMSO as the collecting solvent. DMSO absorbs water and the rate of absorption is higher when the humidity level and the temperature are raised. The temperature and humidity were higher during day 2 and all CIP10/DAN systematically overflowed during the 30 minutes of sampling. This phenomenon was not observed with the CIP10/MP as TBP is used instead of DMSO. In order to minimize the impact of water absorption by DMSO, 1.5 ml of DMSO should be used in the CIP10 rather

**Table 1.** Recovery of known spiked concentrations.

Method	True concentration ( $\mu\text{g/ml}$ )	Mean measured concentration ( $\mu\text{g/ml}$ )	% Recovery
Impinger MP/toluene	0.79	0.77	98 $\pm$ 4
MP 13-mm filter	0.84	0.85	101 $\pm$ 1
CIP10/MP	0.89	0.89	100 $\pm$ 1
CIP10/DAN	2.0	1.8	88 $\pm$ 4



**Figure 1.** TRIG comparison in spray foam using the jar.

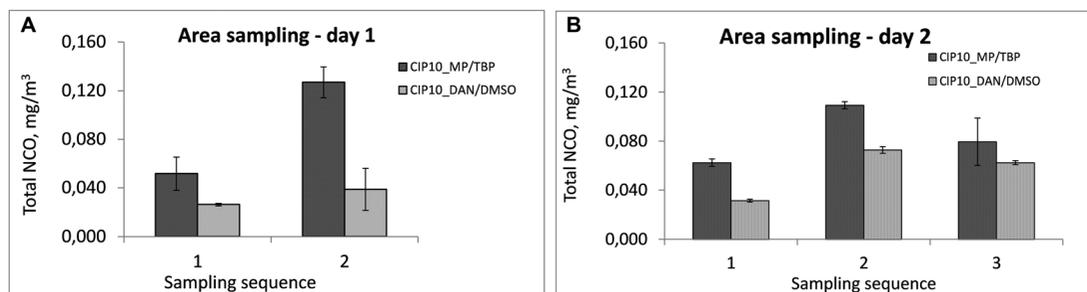
than 2 ml as recommended by the manufacturer. The use of a lower volume prevents overflowing for 30 minutes of sampling as the DMSO does not expand enough to overflow the cup size in these conditions. Nonetheless, the results were judged suitable to move forward with field evaluations in a real workplace and, once again, the CIP10 appears to be as efficient as the impinger for the collection and derivatization of MDI aerosols in the spray foam process.

### Field comparison in real workplaces

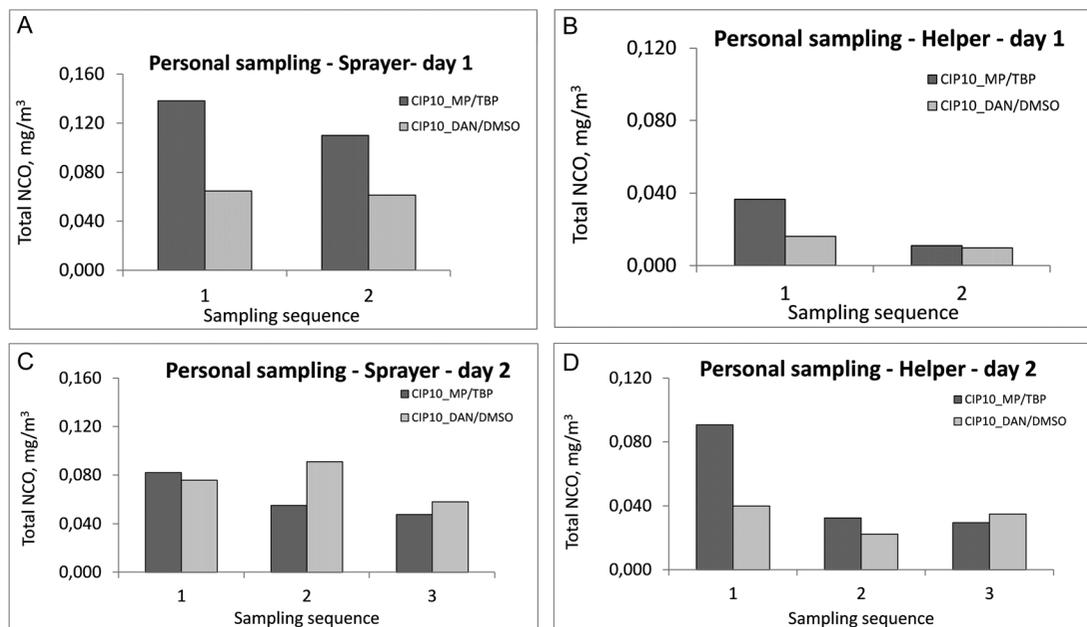
The CIP10/MP provided results similar to the impinger in the comparison conducted using the jar. Since impingers have significant drawbacks for personal sampling, it was decided to use the CIP10/MP method as the reference method for the two sampling campaigns in real spray foam workplaces with both personal and ambient (area) samples. The area sampling results for the two days are presented in Fig. 2. Each bar presented is a mean of two duplicate samples ( $n = 2$ ). Differences are observed for TRIG concentrations provided by the CIP10/DAN versus the CIP10/MP (reference method). The difference appears greater on day 1. Interestingly, the trend does not match what was observed in the comparison using the jar. In this case, the CIP10/DAN method provides lower results than the CIP10/MP method. This could either be explained by the humidity levels or by another unknown fact linked to the chemistry of the method. Significant water absorption from air humidity was observed in the DAN samples and the presence of water in the collecting medium could affect the useful amount of medium necessary to collect the MDI. Also, an unknown phenomenon related to the chemistry of the method not being controlled during the field sampling has not been completely ruled out. The same observation was made with the personal samples, as can be seen in Fig. 3 where each bar presented is a single value ( $n = 1$ ). Equal or lower TRIG concentrations as compared to the reference method were measured with the CIP10/DAN.

The use of DMSO is a major limitation with the CIP10/DAN due to its hygroscopic character and, perhaps combined with an unknown phenomenon related to the chemistry of the method, prevents assessment of the DAN approach to its full value. Even if the volume of the collecting medium was reduced in the cup to avoid overflowing, the efficiency of sample collection is not, on average, equivalent to the reference method. Nevertheless, the CIP10 itself, with an appropriate sampling medium such as TBP/MP, was successfully shown to be useful in real spray foam workplaces for efficient collection of MDI aerosols for both personal and ambient samples.

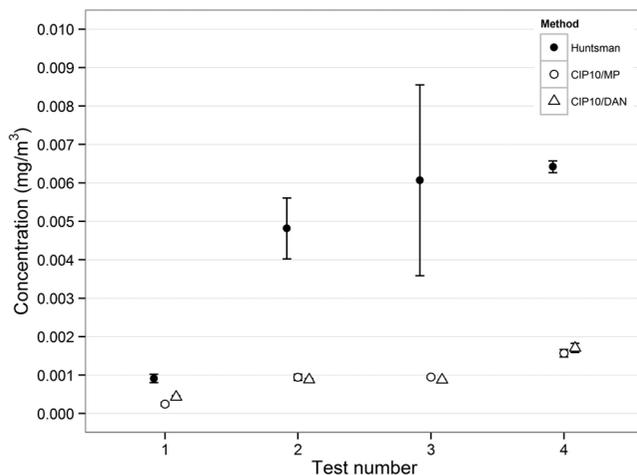
The last workplace sampled was an OSB plant. In the OSB process, the pMDI is used without polyol, reacting with water in the wood particles to bind them together through the formation of polyureas. For this evaluation, the MP 13-mm filter method was used as the reference method for comparison with the CIP10/MP and the CIP10/DAN. The homogenizer jar was not used since the emission source was constant and the airflow directional variation was judged negligible. The humidity level was low during the sampling, between 25 and 27%. The MMAD measured by our group was  $0.6 \mu\text{m}$  (GSD = 3.9). This result, however, is not specific to isocyanate airborne particles but represents the particle-size distribution of all the particles collected by the impactor stages and final filter. However, assuming that all wood particles are coated with pMDI, this result means that airborne pMDI particles are mostly in the respirable fraction. This is consistent with data obtained by a modified version of the ASSET EZ4-NCO (Gylestam *et al.*, 2014a) in a similar location in another OSB production plant, in which 57% of the sampled airborne monomer MDI (2,4' and 4,4' isomers) particles were below  $4 \mu\text{m}$  (Vangronsveld and Ahrika 2015). The proportion of MDI monomer in vapor form was also measured by our group at 37% and 16%, respectively. The comparison between the samplers is presented in Fig. 4. Each bar



**Figure 2.** Area sampling results for spray foam. (A) Day 1 and (B) Day 2.



**Figure 3.** Personal sampling results for spray foam. (A) Sprayer - day 1; (B) Helper - day 1; (C) Sprayer - day 2; and (D) Helper - day 2.



**Figure 4.** TRIG comparison in OSB process.

presented is a mean of triplicate samples ( $n = 3$ ). As can be seen in Fig. 4, mean TRIG concentrations were 80% (95% CI [51, 110]) and 79% (95% CI [50, 108]) lower for the CIP10/MP and CIP10/DAN samples, respectively, as compared to the MP 13-mm filter method. This behavior could be linked, as explained above, to the size of the particles present in the OSB plant and also to the presence of MDI in vapor form. It is suspected to be a challenge to collect vapors and small particles below  $2.8 \mu\text{m}$  with the CIP10 (Görner *et al.*, 2006). Based on

the literature, the collection efficiency for the CIP10 is ~20% for particles smaller than  $1 \mu\text{m}$  (Görner *et al.*, 2006). The results suggest a limitation that needs to be more fully investigated for isocyanate sampling using the CIP10. This potential limitation may also prevent assessment of the DAN approach to its full value. As some levels were detected with the DAN, the chemistry seems to work, but cannot provide results comparable to those provided by the reference method. More development would be needed to conduct sampling with DAN in the

OSB process. DAN would need to be used in a different sampler than the CIP10, which does not seem to be an appropriate sampler for the OSB process due to the potential presence of small particles and vapors.

## Conclusion

DAN reagent continues to appear to be a promising new tool for monitoring TRIG, facilitating isocyanate function measurements from the monomer, the oligomers and the unreacted polymer as well. In the current work, DAN reagent was introduced in a CIP10 to sample a polyurethane spray foam environment and a wood product binder environment. Although significant TRIG levels were monitored using the DAN reagent, inconsistencies with the levels measured by the reference methods were obtained. The chemistry of the DAN reagent appears suitable, but the method's limitations when used in combination with a CIP10 are mainly related to the medium in which the chemical reaction occurs. DMSO is the solvent used for the chemical reaction, but it led to major drawbacks during sampling with a CIP10 linked to its hygroscopicity. The DAN method with DMSO would be more optimal with another sampling device, such as an impinger operated at 1 l/min. On the other hand, the CIP10 used with an adequate collection medium such as TBP/MP was shown to be an innovative and efficient way to collect MDI aerosols, as the impinger would have done, in the spray foam environment. Nevertheless, the CIP10 may have reached its limit in the OSB process, where vapors and particles below 1 µm were not collected as efficiently as the reference method. Further investigation of this limit is needed to confirm this hypothesis.

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## Disclaimer

The article contents, including any opinions and/or conclusions expressed, are those of the authors. The authors declare no conflict of interest relating to the material presented in this Article.

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