# ASSESSMENT OF HUMAN EXPOSURE TO TOLUENE DIISOCYANATE

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**ABSTRACT. – Assessment of human exposure to toluene diisocyanate.** Toluene diisocyanate (TDI), an aromatic compound, may be dangerous for human health. Diisocyanates have wide industrial use in the fabrication of flexible and rigid foams, fibers, elastomers, and coatings such as paints and varnishes. Isocyanates are known skin and respiratory sensitizers, and proper engineering controls should be in place to prevent exposure to isocyanate liquid and vapor; exposure to TDI vapors is well documented to increase asthma risk. The study focused on the exposure of workers and nearby populations to toluene diisocyanate in a Polyurethane Foam Factory located in Baia Mare, Romania. Workplace air measurements were performed in different departments of the plant, after sampling either in fixed points or as personal monitoring. Sampling in four different locations of Baia Mare town was carried out, - during and after the foaming process. TDI sampling was performed on silica cartridge followed by GC-MS analysis. TDI concentration at workplace was lower than 0,035 mg/m³, which represents the permissible exposure limit, while in the city the TDI concentration had shown values below 0,20 µg/m³. Health assessment of a group of 49 workers was based on questionnaire interview, determination of TDI antibodies and lung function tests. Data collected until this stage do not show any negative effects of TDI on the employees health. Since this plant had only recently begun operating, continuous workplace and ambient air TDI monitoring, along with workers health surveillance, is deemed necessary.

**Key words:** toluene diisocyanate, exposure assessment, environment, professional environment, health.

## 1. INTRODUCTION

Toluene diisocyanate is one of the most common aromatic isocyanates used in the production of polyurethane polymers. Polyurethanes are broadly used in high resiliency flexible foam seating, rigid foam insulation panels, microcellular foam seals and gaskets, durable elastomeric wheels and tires, automotive suspension bushings, electrical potting compounds, high performance adhesives and sealants, Spandex fibers, seals, gaskets, carpet underlay, and hard plastic parts (such as for electronic instruments). The global consumption of polyurethane raw materials is climbing, having an average annual growth rate of about 5% (Avar, 2008); this represents a rising industry, making very important the development of safer and less polluting manufacturing methods.

TDI (molecular formula $C_9$-$H_6$-$N_2$-$O_2$) is the most volatile of the isocyanate compounds. In its commonest form TDI is a colorless to pale-yellow liquid consisting of a mixture of 2,4- and 2,6-diisocyanates isomers which will polymerize readily in air. It has a high vapor pressure (0.025 mmHg at 25 $^0$C; boiling point 115-120 $^0$C) and must be strictly controlled to prevent fugitive emission losses to atmosphere. TDI liquid must be managed carefully as, at temperature below 8-14 $^0$C, the substance will begin to freeze, creating special problems in outdoor handling activities for much of the year.

Toluene diisocyanate (TDI) is the second highly produced diisocyanate, accounting for 34.1% of the global isocyanate market in 2000 (Randall and Lee, 2002). It is a hazardous aromatic compound synthesized in six steps (Randall and Lee, 2002), in which phosgenation of corresponding amines represents the main technical process for the manufacture of isocyanates. The amine raw materials are generally manufactured by the hydrogenation of corresponding nitro compounds; in this case, toluenediamine (TDA) is manufactured from dinitrotoluene, which then converted to toluene diisocyanate (TDI).

Isocyanates are known skin and respiratory sensitizers, and proper engineering controls should be in place to prevent exposure to isocyanate liquid and vapor; exposure to TDI vapors is well documented to increase asthma risk (Allport et al., 2003). Occupational asthma and hypersensitivity pneumonitis as a direct result of introduction to isocyanates in general and TDI in particular have been extensively researched, predominantly in last 10 to 15 years (Ott et al., 2007; Aul et al., 1999). Other forms of hypersensitivity manifestation have also been linked to diisocyanates and TDI professional contacts (dermatitis – Estlander et al., 1992; eye - conjunctiva, mucosal irritation – Omae et al., 1992; Littorin et al., 2007).

There is no permissible exposure limit for TDI in the residential areas in Romania. For the Foam Factory in Baia Mare the maximum concentration of TDI allowed in community atmosphere is 1 $\mu g/m^3$ for 30 minutes.

## 2. METHODS

### 2.1. Environmental sampling and data collecting methodology

TDI sampling was performed both in the community ( Baia Mare) and at the workplace, by either fixed point or personal monitoring technique. Fixed point (-ambient sampling) was carried out at breathing level (1.5 m) with a pump – silica cartridge device. Air sampling was correlated with duration of the pollutant emission. Personal monitoring is a sampling method very efficient for the exposure assessment of workers to occupational hazards, as it is a shift measurement timing. This method requires workers wearing the ensemble consisting of a personal pump device and the silica cartridge.

The first step is to collect the environment data correctly. After the sampling points are set up, the stand and the auxiliary devices are fixed, the pump must be calibrated for the desired flow. The sample is taken on a silica cartridge (adsorbent tube). The pump is started and air is crossing the silica cartridge with a known, steady flow (0.25 l/min) for 20-30 minutes. Absorber tube ends are sealed and kept cold (4 °C) until analysis.

Imission measurement of toluene diisocyanate in the community involve sampling on a silica gel cartridge in four points inside the city of Baia Mare, sites located at different distances from the plant.

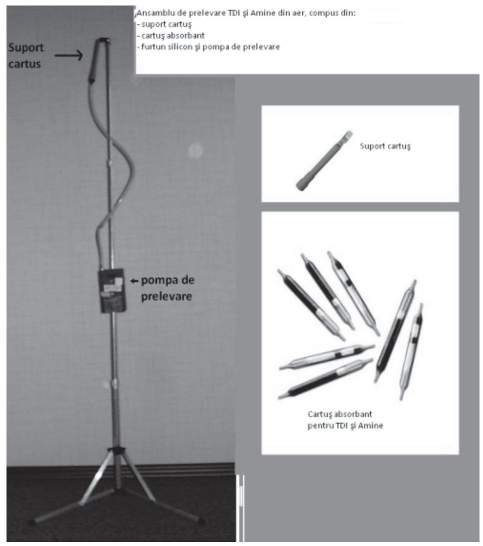


**Fig. 1.** ***The TDI sampling ensemble***

In these points, measurements were made for three consecutive days, five probes for each location being sampled every day. Sampling was performed as it follows: during the foaming process three samples (at the same time) were taken on each point, and two more samples, at 4 and 8 hours after the ending of the foaming process, were also taken in each point. This operation was repeated during the next two days. The sampling time for the first three tests depends on the foaming process duration (the time it takes place is divided by three). For the other two samples, the sampling time was 30 minutes. The sampling flow rate for toluene diisocyanate was 0.25 l/min.

- First point is situated on Motorului 8 street, at a distance of approximately 1000 m from the factory;
- The second point is situated on Culturii 8 street, at 2750 m away from the factory;
- The third point is on the Vasile Lucaciu 126 street, at a distance of 4750 m from the factory;
- The last point is situated on the Uzinei 3 street, at a distance of approximately 7450 m from the factory.

Inside the factory, two measurements were performed at fixed points in the foaming department, at the ends of the plant: the first one next to the mixer in which take place the addition of the components and the second one at the end of the plant were foam block is already formed. The sampling time for this measurements was 100 minutes at a flow rate of 0.25 l/min.

In this department (foaming), a series of personal monitoring were also completed. Three workers with the workplace along the plant had worn the ensemble formed by personal pump and silica cartridge. These workplaces were situated at the beginning of the plant, next to the mixer, at the middle of the conveyor belt and at the end of the line. The sampling in this case was during one foaming process, with a flow rate of 0.25 l/min.

More personal monitoring was made in the cutting area for two workplaces. The sampling time was 120 minutes with the flow rate of 0.25 l/min.

### 2.2. The analysis methodology

The purpose of this procedure is to determine TDI air concentration, after adsorption and desorption on activated silica gel cartridge. The method described is applicable to both industrial isomers (2,4 - and 2,6 - TDI). The principle of this method is quantitatively transfer of the sample from the silica gel cartridge in a vial followed by extraction of the toluene diisocyanate with methanol. The extract is afterwards measured using a mass spectrometry chromatograph (GC-MS Shimadzu QP2010).

Laboratory analysis is gas chromatography coupled with mass spectrometry and begins with preparing the devices and the column according to instructions. After this, the calibration curve must be drawn; initially two series of standard solutions were prepared with the solvent. The extraction has been made in the following concentrations: 40 µg/l; 60 µg/l; 80 µg/; 100 µg/l. The standards were measured by recording the chromatogram for each standard solution. The device software plots the calibration curves, these being linear curves. Calibration curve should be checked no less than at 12 months, and always when using new reactors. Reagents utilized in this method are GC-purity methanol and E1 standard TDI (Merck supplier). The sample processing is done by breaking the sample cartridge in a lidded vial, then adding 2 ml of methanol, followed by one minute stirring in order to make the extraction. The extract is filtered and placed in a smaller vial that is sent to the GC analysis. Reading the results occurs by measuring the chromatogram under specific working method; the amount of TDI (the area in the chromatogram) is read from the calibration curve.

### 2.3. Health data collection and analysis

As the monitoring process began right from the opening of the factory, a group of presumably unexposed new workers has been initially evaluated throughout a health questionnaire, pulmonary function tests, serum TDI antibodies and individual polymorphisms, as well. At a 6 months follow up, lung function tests and blood sampling were repeated, while the questionnaire was reapplied to the subjects. TDI antibodies and individual polymorphisms are not discussed at this moment.

Trained interviewers filled in the questionnaires independently. Questions were aimed to record respiratory health problems and allergic background in specific details. Smoking habits and close contact with pets or other animals, as well as home environment, were briefly asked in the questionnaire, while a special attention was paid to the work practice – personal protective equipment, and exposure control measures such as ventilation and hygiene conditions, along with questions on workers' compliance to safety rules. A matter of interest was the issue of previous contacts with polyurethanes, explicitly TDI and other diisocyanates; sections of the questionnaires covered information about pre-employments and exposure to insulating construction foams or sprayed paints.

The lung function tests were performed and their results interpreted by occupational healthcare professionals. Standard spirometry parameters were pursued and on their bases, the specific diagnostics were set.

For final interpretation of the gathered data, the statistical procedure of Chi-square test was used. Chi-square (noted $\chi 2$) is generally considered the statistical indicator of differences among proportions (percentages) and it can reduce the foregone conclusions emerged from comparing non-homogenous factions.

## 3. RESULTS

### 3.1. Environmental monitoring

During 2010, there were four sets of measurements performed for determination of airborne TDI concentrations in Baia Mare:

- The first measurements took place on 16, 17, 18 February 2010;
- The second set of measurements took place on 23, 24, 25 June 2010;
- The third set of measurements were made in 08, 09 and 10 September 2010
- The last set of measurements took place on 16, 17, 18 November 2010.

**Table 1.** ***Results from inside plant measurements***

| | **Workplace** | **TDI concentration** | **STEL (15 min)** | **TWA (8 h)** |
|---|---|---|---|---|
| | | **mg/m3** | | |
| Cutting area (individual monitoring) | Long-blocks cutting operator | <0.0002 | 0.14 | 0.035 |
| | Cutting operator | <0.0002 | 0.14 | 0.035 |
| | | | | |
| Foaming hall (individual monitoring) | Mixer operator (engineer) | <0.0002 | 0.14 | 0.035 |
| | Paper operator | <0.0002 | 0.14 | 0.035 |
| | Cutting operator | <0.0002 | 0.14 | 0.035 |
| | | | | |
| Foaming hall (fixed point) | Near mixer tank (beginning of plant) | <0.0002 | 0.14 | 0.035 |
| | End of plant (emergence of foam blocks) | <0.0002 | 0.14 | 0.035 |

Data obtained after analyzing the TDI samples from the factory are presented in table 1. The results obtained after analysis of these samples were lower than 0.20 $\mu g/m^3$ , which represents the detection limit of the device.

As shown in table 1, the concentrations of TDI from the samples inside the factory are very low, lower than the detection limit of the device. This can be explained due to advanced technology in manufacturing facilities, which are all automated.

### 3.2 Health status monitoring

In questionnaire responses, for increased relevance of this analysis, the cohort of subjects was divided into three levels of possible exposure at the working station, ranging from level I (the most significant) to level III (least potential exposure); these subgroups will be identified as "departments" in paragraphs below.

Table 2 summarizes the frequency of positive answers in three departments with diverse levels of assumed exposure. Categories listed below reflect the main lines of interest in projected finales.

**Table 2.** ***Positive answers percentage in departments***

| Category / Department (%) | Foaming (level I) | | Cutting (level II) | | Administrative (level III) | | *Total* | |
|---|---|---|---|---|---|---|---|---|
| | Initial | 6 months | Initial | 6 months | Initial | 6 months | **Initial** | **6 months** |
| *Diagnosed respiratory disease* | 0.00 | 0.00 | 0.00 | 0.00 | 0.00 | 6.67 | **0.00** | **2.08** |
| *Respiratory symptoms* | 4.08 | 0.00 | 8.16 | 6.25 | 6.12 | 2.08 | **18.36** | **8.33** |
| *Recent respiratory ailment* | 0.00 | 2.08 | 6.12 | 12.50 | 4.08 | 2.08 | **10.20** | **16.67** |
| *Hypersensitivity* | 2.04 | 0.00 | 2.04 | 0.00 | 2.04 | 0.00 | **6.12** | **0.00** |
| *Allergic symptoms* | 0.00 | 2.08 | 0.00 | 6.25 | 0.00 | 6.21 | **0.00** | **14.58** |
| *Smoking habits* | 12.24 | 12.50 | 16.32 | 16.67 | 12.24 | 12.50 | **40.81** | **41.67** |
| *Other TDI exposure* | 22.44 | 4.16 | 22.44 | 4.16 | 22.44 | 8.33 | **67.34** | **16.67** |
| *Equipment satisfaction* | 26.53 | 22.91 | 36.73 | 35.41 | 24.48 | 31.25 | **87.75** | **89.58** |

The only comparison that holds statistical significance ($p \leq 0.05$) is that between new exposures to diisocyanates in the two time-lines, since drastically fewer had occurred in the 6 months interval. Concerning performed lung tests, in the group of 44 valid lung function tests, 39 (88.63%) were considered within physiological limits while five (11.37%) persons were diagnosed with mild to moderate peripheral obstructive ventilatory dysfunction. The mean prevalence of obstructive dysfunction is considered to be around 12% in general population (Weaver LK et all, 2009; Kogevinas et all, 1999). Further on, we considered prevalence of diagnosed disease in our group in relationship to previously mentioned departments, which theoretically signify different levels of potential exposure. 4.55 % of the subjects that presented obstructive dysfunction were in the first group, 6.82 % were from the “medium exposure” subgroup and none from the Administrative section.

In order to establish an indication of patterns to be observed in further analysis as more data accumulates, we tried to make a direct comparison between frequencies of declared respiratory symptoms and objective spirometry results. Tables below present this cumulated information.

**Table 3.** ***Connection between respiratory symptoms and dysfunction***

| **(%)** | *Initial Respiratory symptoms* | **6 months Respiratory symptoms** | **Obstructive dysfunction** |
|---|---|---|---|
| **Total** | *18.36* | **8.33** | **11.37** |
| I | *4.08* | **0.00** | **4.55** |
| II | *8.16* | **6.25** | **6.82** |
| III | *6.12* | **2.08** | **0.00** |

Differences between first two columns have proved no statistical significance, as already stated through total questionnaires investigation; however, a fairly strong correlation has been brought forward when initial and follow-up declared symptoms were set beside diagnosed obstructive dysfunctions.

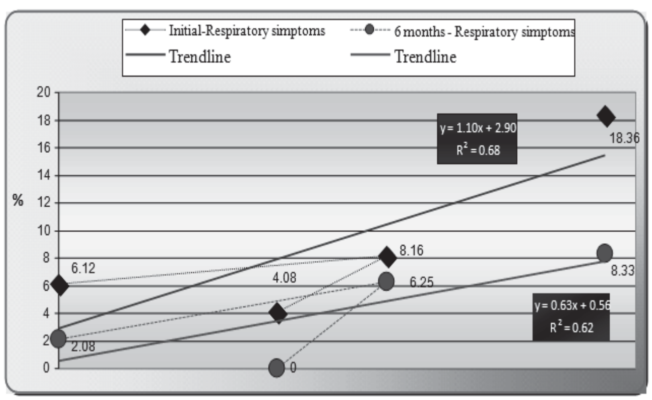


**Fig. 2.** ***Regression curves***

The second figure shows the simple linear regressions for the aforementioned factors, pointing out a similar ascendant trend and a better correlation of total lifetime responses (initial questionnaire) with the resulted affections. Regression equations may be found in the image.

Nonetheless, as seen from the picture, the parallel is not conforming to the arrangement of departments in presumed exposure order; most asserted symptoms are in the second group, both initially and at follow-up.

## 4. DISCUSSIONS AND CONCLUSIONS

The results of all the TDI samples were lower than the detection limit of the device (0.20 µg/$m^3$).

The health assessment segment of this monitoring was based upon the assumption that there are different levels of exposure risk to TDI, in relation to specific workplace demands inside the plant. Overall, few resulting correlations in health survey parameters had statistical significance, and no association could be drawn between these outcomes and the corresponding working place environment – the presumed level of risk considering chemical exposure.

Furthermore, environmental data collected to this point give no additional indication as to whether the initial supposition was correct. However, these results are not surprising when keeping in mind that this health information is intermediary and situated at a very early point in terms of relevance; from a physiological point of view, manifestation of premature clinical effects would have been unexpected. Moreover, a single set of probes measuring TDI levels inside the plant might prove insufficient for a correct and complete estimation of emissions at workplace, especially during foaming process, when large quantities of diisocyanates are utilized.

Clinical literature published data sustain the knowledge of serious health effects (e.g. lung function tests changes and bronchial asthma) developed in association with very low levels of airborne TDI. Considering this fact when taking our results into account, we cannot support the presumption that measurements below the level of detection accrue in no adverse health effects.

Future sets of testing, both subject based and environmental measurements, will take place for the next three to four years at an estimated frequency of twice a year (approximately at six months).

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