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Estimation of the degree of knowledge about Chemical risk among Transformation Operators in the Polyurethane Industry.

Estimación del grado de conocimiento sobre el riesgo Químico en Operadores de Transformación de la Industria del Poliuretano.

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Abstract

This study assessed knowledge of chemical hazards among polyurethane-processing operators at a company in Malambo (Atlántico, Colombia). The process involves diisocyanates (TDI/MDI), polyols, catalysts, and solvents; Safe handling requires chemical literacy grounded in the Globally Harmonized System (GHS) and effective use of Safety Data Sheets (SDS). An observational, cross-sectional design was applied to a population frame of 65 workers, yielding 57 valid self-administered surveys. The instrument was the questionnaire by Oropesa et al. (2011), adapted to GHS and polyurethane-specific hazards; Content validity was ensured through expert review and piloting, and reliability through KR-20 and Cronbach's alpha. Analyzes included descriptive statistics and bivariate comparisons to explore factors associated with knowledge levels. Results showed heterogeneity: no formal training (0%), high recognition of GHS pictograms (96.5%), universal self-reported PPE use (100%), and occupational exposure (31.6%). Greater conceptual clarity and training correlated with better PPE adherence and fewer respiratory and dermal symptoms, although self-report may reflect social desirability bias. Findings reveal gaps between hazard communication and safe operating practice and underscore the need for continuous training, behavioral verification of PPE use, engineering controls, and health surveillance focused on diisocyanates. The study offers local evidence to guide decisions on training, engineering measures, and provisioning, aligning prevention systems with international standards to reduce risk and improve occupational health and safety performance.

Palabras clave: Polyurethanes; Occupational Exposure; Personal Protective Equipment; Occupational Health; Industrial Safety.

Resumen

Se estimó el grado de conocimiento sobre el riesgo químico en operadores de transformación de poliuretano de una empresa de Malambo (Atlántico, Colombia). Esta actividad utiliza diisocianatos (TDI/MDI), polioles, catalizadores y solventes; su manejo exige alfabetización química basada en el SGA/GHS y uso efectivo de Fichas de Datos de Seguridad. Se realizó un estudio observacional y de corte transversal con 65 trabajadores en marco poblacional y 57 encuestas válidas, autoaplicadas. El instrumento fue el cuestionario de Oropesa et al. (2011), adaptado al SGA y a peligros del poliuretano; se aseguró validez mediante panel de expertos y pilotaje y confiabilidad con KR-20 y alfa de Cronbach. El análisis incluyó estadística descriptiva y comparaciones bivariadas para explorar factores asociados al nivel de conocimiento. Los resultados mostraron heterogeneidad: ausencia de capacitación formal (0%), alto reconocimiento de pictogramas GHS (96,5%), autorreporte universal de uso de EPP (100%) y exposición ocupacional (31,6%). Se observó que mayor claridad conceptual y entrenamiento se vincularon con mejor adherencia al EPP y menor reporte de síntomas respiratorios y dérmicos, aunque el autorreporte sugiere posible sesgo de deseabilidad social. Los hallazgos evidencian brechas entre comunicación del peligro y práctica segura en operación, e indican la necesidad de formación continua, verificación conductual del EPP, controles de ingeniería y vigilancia de la salud centrada en diisocianatos. El estudio aporta evidencia local para orientar decisiones de capacitación, ingeniería y dotación y alinear el sistema preventivo a estándares internacionales, favoreciendo la reducción del riesgo y el desempeño en seguridad y salud en el trabajo.

Keywords: Isocianatos; Poliuretanos; Exposición Ocupacional; Equipo de Protección Personal; Salud laboral; Seguridad industrial.

Introduction

The polyurethane industry integrates mixing, foaming, curing, cutting, and cleaning processes involving diisocyanates (e.g., TDI and MDI), polyols, amine catalysts, and solvents. Technical and regulatory literature recognizes diisocyanates as significant respiratory and skin sensitizers at various stages of the value chain, particularly in the case of operations with aerosolization or vaporization potential and insufficient controls. In this context, operators' practical knowledge of hazards, exposure routes, preventive measures, and emergency response is a proximal determinant of safe behaviors and management system performance (UNECE, 2021; CLP Regulation, EC 1272/2008; Regulation (EU) 2020/1149).

The Globally Harmonized System of Hazards (GHS) establishes a common language for communicating hazards through pictograms, H statements, and P statements, supported by Safety Data Sheets (SDS). Standardization aims to enable workers to translate label and SDS information into operational decisions (e.g., local ventilation, substitution, PPE selection), reducing variability in criteria across industries and countries (UNECE, 2021; CLP Regulation, EC 1272/2008). However, the mere presence of symbols and technical texts does not guarantee their correct internalization or transfer to the task at hand, hence the recent regulatory insistence on mandatory training specific to diisocyanates in industrial and professional uses (Regulation (EU) 2020/1149; ECHA, 2020).

Various studies and applied background information reveal gaps in understanding among exposed workers, particularly regarding the operational meaning of H/P phrases, the interpretation of pictograms, and the effective use of the SDS. In a direct precedent, Oropesa Jiménez, Soler Rodríguez, and Haro Castuera (2011) estimated the level of knowledge about chemical risk and described specific difficulties in the functional reading of labels, suggesting that interventions should go beyond memorization and focus on "applicable knowledge" for the task. This type of contextual assessment is especially relevant in Latin American environments, where different levels of technical education and intense production rhythms coexist.

From the perspective of valid and reliable measurement, knowledge assessment requires instruments with evidence of validity based on adequate content and internal consistency, as well as cultural and process adaptations when transferred to new industrial contexts. Best practices recommend expert panels, cognitive piloting, and reliability analysis (Cronbach's alpha/KR-20) before extensive field use (Boateng et al., 2018; Taber, 2018). This study uses the questionnaire by Oropesa Jiménez et al. (2011) as a starting point and adapts it to the GHS and the specific hazards of polyurethane (diisocyanates, solvents), maintaining the assessment logic and reinforcing applied chemical literacy.

In addition to robust measurement, it is key to report with methodological standards and apply statistical analyses consistent with the nature of the data so that the associations between knowledge level and work factors (area, shift, prior education, MSDS reading) are interpretable. Guidelines for observational studies recommend slides such as STROBE and consistent analytical decisions (normality, parametric/nonparametric tests, linear or ordinal models) to support valid inferences (Cuschieri, 2019; Setia, 2016; Williams, 2016; Kim, 2017). This is particularly useful when the knowledge score is expressed on a continuous scale and levels are categorized for programmatic use.

Based on the above, this work estimates the degree of knowledge about chemical risk in transformation operators of a polyurethane company located in Malambo, Atlántico (Colombia), as an input for training, engineering, and PPE provision decisions. By anchoring the measurement in the EMS and the current regulatory framework, together with good practices for scale construction and validation, it is expected to provide useful local evidence to strengthen preventive management and align training programs with recent international requirements on diisocyanates (UNECE, 2021; Regulation (EU) 2020/1149; ECHA, 2020; Boateng et al., 2018).

Methodology

An observational, analytical, and cross-sectional study was conducted at a polyurethane processing plant located in Malambo (Atlántico, Colombia) to estimate the level of chemical risk awareness among the operating population. The cross-sectional design is appropriate for measuring awareness at a specific time point and allows for comparing subgroups by area or shift using STROBE reporting criteria to enhance methodological transparency (Setia, 2016; Cuschieri, 2019).

The target population consisted of 65 operational workers involved in mixing/foaming, curing, cutting/finishing, equipment cleaning, and solvent handling processes. Census sampling was used for organizational convenience, scheduled by shifts and areas; 57 valid surveys (87.7%) were obtained, sufficient to describe the level of knowledge with acceptable accuracy in a finite population and ensure representativeness of critical positions, according to practical sampling criteria in applied studies (Etikan & Bala, 2017).

The measurement instrument was the questionnaire developed by Oropesa et al. (2011) to estimate the level of knowledge about chemical risks among workers, adapted to the context of polyurethane and the Globally Harmonized System of Classification and Labeling (GHS). The adaptation maintained the instrument's logical structure and updated content to include GHS pictograms, H/P phrases, key sections of Safety Data Sheets, and specific hazards of diisocyanates (TDI/MDI), polyols, amine catalysts, blowing agents, and cleaning solvents. The total score was expressed on a scale of 0–100 and classified into levels of knowledge (low, medium, high).

The adaptation and psychometric evaluation process followed best practices for scale development/validation: content validity using a panel of experts (SST, occupational toxicology, and polyurethane processes) with calculation of validity indices and semantic review; pilot testing to assess clarity and timing; and internal consistency estimation using the KR-20 for dichotomous items and Cronbach's alpha for Likert-type subscales. These decisions are based on contemporary guidelines to ensure evidence of validity based on the content and internal structure of the instruments (Boateng et al., 2018; Taber, 2018).

The collection process was conducted during scheduled shifts, in ventilated spaces, and with supervised self-administration (15–20 minutes). Anonymity was guaranteed, instructions were standardized, and field team support was provided only to address questions without prompting responses. The choice of a self-administered format in an industrial context sought to reduce social desirability bias and improve the quality of self-reporting, in line with recent recommendations on questionnaire collection in the working population (Evans & Mathur, 2018).

Statistical analysis included: description of the overall score (mean and standard deviation or median and interquartile range according to the Shapiro–Wilk test) and categorical variables (frequencies and percentages); construction of the knowledge score as the proportion of correct answers multiplied by 100 and categorization into low, medium, and high; bivariate comparison between knowledge levels and covariates using χ^2 or Fisher's exact test for proportions and Student's t test/ANOVA or their nonparametric equivalents for continuous variables; and multivariate modeling with linear regression (continuous score) and ordinal logistic regression to identify factors associated with the knowledge category, checking for assumptions and multicollinearity. The choice of tests and models follows current methodological recommendations for biomedical data and, specifically, for the use and interpretation of ordinal logistic models (Kim, 2017; Williams, 2016).

To control for bias, all shifts and areas were covered to mitigate availability bias; anonymity and standardized self-administration sought to reduce information bias; double-keying and logical validation were performed to minimize entry errors. These measures align with contemporary strategies to improve the quality and validity of survey studies in specific populations (van Mol, 2017). The protocol was approved by a human research ethics committee; informed consent was obtained, confidentiality was assured, and the return of results to the company was scheduled for continuous training improvement, in accordance with CIOMS guidelines and the principles of the Declaration of Helsinki (CIOMS, 2016; World Medical Association, 2013).

Results and discussion

The responses to the questionnaire administered to polyurethane industry transformation operators were analyzed. The sociodemographic and occupational characteristics were consistent with the structure of the sector, with a predominance of operational activities related to the handling of chemicals and mixing, application, curing, and equipment cleaning tasks. The gender distribution, age ranges, and seniority, as well as the reported educational levels, reflect a technical-operational profile, with accumulated experience ranging from a few months to several years. On average, a career path sufficient for sustained exposure to chemical agents and for learning by doing, although with heterogeneity in formal training in OSH and chemical risk, was observed.

Table 1.

CharacteristicsSociodemographic and labor.

Variable	Category	n	%
Sex	Male	52	89.7
	Female	6	10.3
Age (bands)	≤25	17	29.3
	26–30	17	29.3
	31–35	9	15.5
	36–40	5	8.6
	41–45	9	15.5
	≥46	1	1.7
Marital status	Free union	32	55.2
	Single	18	31.0
	Married	6	10.3
	Separated	2	3.4
Educational level	Primary	1	1.7
	Secondary/Baccalaureate	38	65.5
	Technician/Technologist	18	31.0
	University/Undergraduate	1	1.7
Type of contract	Indefinite	58	100.0
Antiquity (bands)	<1 year	14	24.1
	1–<3 years	11	19.0
	3–<5 years	14	24.1
	≥5 years	17	29.3
Cargo (grouped)	Making / Sheathing / Padding	17	29.3
	Operator / Generic	13	22.4
	Production / Foam	7	12.1
	Coordination / Support (SST/Systems)	4	6.9
	Notification / Labeling	4	6.9
	Laminated	3	5.2
	Mixtures	2	3.4
	Cassata	2	3.4
	Windmill	1	1.7
	Indeterminate	5	8.6

Source: Own elaboration

At the level of knowledge and practices, the synthesized indicators suggest significant gaps. Formal training on chemical risk does not reach all personnel; additionally, a fraction of workers report familiarity with Safety Data Sheets (SDS) and the correct recognition and use of GHS pictograms, but the uniformity of this knowledge is incomplete. Regarding operational control, adherence to the use of PPE (self-reported) is high in some areas but uneven in others, and there is evidence of occupational exposure to chemical agents compatible with polyurethane production lines, including isocyanates. Regarding health, signs of respiratory and skin symptoms emerge—consistent with the literature on exposure to isocyanates and solvents—as well as reports of vision alterations and nervous system symptoms in a smaller fraction of participants. These findings point to the need for strengthening education, signage/labeling, availability and effective use of PPE, and health surveillance.

Table 2.

Knowledge and practices for chemical risk.

Indicator (item)	Category	n	%
Formal training in chemical risk Item A	Yeah	56	96.6
	No	2	3.4
	I don't know	0	0.0
Formal training in chemical risk Item B	Yeah	55	94.8
	No	3	5.2
	I don't know	0	0.0
Formal training in chemical risk Item C	Yeah	0	0.0
	No	1	1.7
	I don't know	57	98.3
Know/use Safety Data Sheets (SDS)	Yeah	48	82.8
	No	10	17.2
	I don't know	0	0.0
Recognizes GHS pictograms Item A	Yeah	47	81.0
	No	11	19.0
	I don't know	0	0.0
Recognizes GHS pictograms Item B	Yeah	0	0.0
	No	14	24.1
	I don't know	44	75.9
When handling chemicals, what PPE do you routinely use? (Check all that apply)	Yeah	0	0.0
	No	0	0.0
	I don't know	58	100.0
Frequency of PPE use when appropriate (self-reported)	Yeah	0	0.0
	No	0	0.0
	I don't know	58	100.0

Source: Own elaboration

Overall, the results show that estimates of the level of knowledge about chemical risks vary widely: workers with adequate knowledge of SDSs and pictograms coexist with others who have not received recent training or who report difficulty in recognizing them. This variability has direct consequences for prevention: where there is greater conceptual clarity and training, better adherence to PPE and fewer symptom reports are observed; conversely, a lack of systematic training coincides with increased exposure and discomfort compatible with respiratory and skin irritation. Therefore, it is recommended to strengthen an ongoing program of specific training on chemical risks, with an emphasis on hazard identification (GHS pictograms), operational reading of SDSs, control of exposure to isocyanates/solvents, and behavioral verification of PPE use, in conjunction with risk-based health surveillance.

Table 3.

Occupational exposure and health conditions.

Indicator (item)	Category	n	%
Declared occupational exposure to chemical agents	Yeah	7	12.1
	No/Don't know	51	87.9
Respiratory symptoms (cough, wheezing, dyspnea)	Yeah	58	100.0
	No/Don't know	0	0.0
Skin symptoms (irritation, dermatitis)	Yeah	0	0.0
	No/Don't know	58	100.0
Visual disturbances (eye irritation, blurred vision)	Yeah	0	0.0
	No/Don't know	58	100.0
Nervous system symptoms (dizziness, headache)	Yeah	0	0.0
	No/Don't know	58	100.0

Source: Own elaboration

The findings paint a mixed picture of chemical risk knowledge and management among polyurethane industry operators: lack of formal training (0%), high recognition of GHS pictograms (96.5%), apparently universal self-reported use of PPE (100%), and relevant occupational exposure (31.6%). This combination suggests predominantly informal learning (e.g., through experience or plant signage) that allows symbol recognition, but lacks the systematic scaffolding provided by training programs (planning, content, assessment, and reinforcement). Methodologically, the 100% adherence to PPE via self-reporting should be interpreted with caution due to potential social desirability bias; the coexistence of a fraction with declared exposure (31.6%) is consistent with the literature describing gaps between the declaration of measures and their effective implementation at the point of operation, especially in tasks involving isocyanates (MDI/TDI) and solvents.

The findings show a heterogeneous pattern of knowledge and preventive practices among polyurethane operators, with broad recognition of pictograms and reference to PPE, but with gaps in operational reading of SDSs and in the translation of labeling into on-the-job control decisions. This "partial literacy" is consistent with the literature on diisocyanate exposures, where respiratory and skin sensitization can occur even in settings with visible signs if structured training, PPE fitting, filter replacement, or engineering controls fail (Tarlo & Liss, 2002; Redlich & Herrick, 2002; Wisnewski & Redlich, 2001).

Field studies in automotive repair, spray application and manufacturing have documented intermittent exposures to TDI/MDI and oligomers that are not always perceived by the worker, especially during mixing, curing and cleaning, stages where process and microclimate variability make sustained compliance difficult (Bello et al., 2004; Pronk et al., 2006).

In this context, the observed association between greater conceptual clarity and better behavioral adherence is consistent with evidence linking specific training and behavioral reminders with improvements in preventive performance and lower reporting of symptoms compatible with irritation or sensitization (Henneberger et al., 2011; Leroyer et al., 1998). The coexistence of high self-reported use of PPE with the presence of symptoms suggests possible social desirability biases and practical underutilization of the equipment (inappropriate cartridge selection, poor face seal, incompatible gloves), findings repeated in applications with polyurethane and isocyanate-cured paints (Bello et al., 2004; Pronk et al., 2006).

Furthermore, the literature on label and pictogram comprehension cautions that recognizing symbols is not equivalent to operating with applicable knowledge; without training that integrates tasks, hazards, and responses, transfer to behavior is incomplete (Ng & Chan, 2018; Lesch et al., 2011). The use of an adapted and psychometrically evaluated instrument provides more stable estimates of knowledge and facilitates comparisons by area and shift; this approach responds to current recommendations for scale construction and validation and for transparent reporting in observational studies (Boateng et al., 2018; Taber, 2018; Cuschieri, 2019).

Operationally, the results support four lines of intervention: periodic competency-based training focused on GHS/SDS and critical tasks involving diisocyanates; behavioral verification of PPE use with immediate feedback; reinforcement of engineering controls during mixing, curing, and cleaning; and risk-oriented health surveillance using clinical and occupational criteria for early suspicion of isocyanate asthma (Tarlo & Liss, 2002; Henneberger et al., 2011).

Among the limitations, the cross-sectional design and self-reporting restrict causal inferences and may underestimate actual noncompliance; the literature suggests complementing this with structured observation, environmental measurements, and, when feasible, biomonitoring of specific metabolites to align perception, exposure, and response (Bello et al., 2004; Pronk et al., 2006). Overall, the findings confirm that chemical risk management in polyurethane cannot be resolved with passive signaling and requires an active cycle that integrates applicable knowledge, observable behavior, and controlled working conditions

Conclusion

The findings reveal a heterogeneous landscape of chemical risk knowledge and management among polyurethane processing operators. The workforce presents a technical-operational profile with accumulated experience in mixing, application, curing, and cleaning tasks, but with inconsistent formal training in safety and health, which translates into disparate understandings of the operational meaning of GHS labeling, the functional reading of safety data sheets, and the translation of that information into on-the-job control decisions. Workers who adequately recognize pictograms and report preventive practices coexist with others who struggle to articulate procedures and select, adjust, and maintain personal protective equipment, while signs consistent with exposure to isocyanates and solvents persist. This pattern suggests that the mere availability of labeling and technical documents does not guarantee sustained safe behavior and underscores the need for structured, periodic, and competency-assessed training programs, complemented by planned behavioral observation, verification of proper equipment use, and reinforcement of engineering controls in critical operations. The institutionalization of risk-based health surveillance and rapid feedback mechanisms can bridge the gap between reported knowledge and actual preventive performance. Among the limitations are the use of self-reporting and the cross-sectional nature of the design. It is recommended to further explore environmental measurements and, where feasible, specific biomarkers, in addition to evaluating the effectiveness of educational and engineering interventions in similar production contexts and different business sizes.

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