



CHALMERS

Identification and Categorisation of Toxic Chemical Gases in Shipping Containers

Bachelor thesis for Shipping and Logistics Program

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CHALMERS UNIVERSITY OF TECHNOLOGY
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PREFACE

This study represents a bachelor thesis completed by Carl Brännhammar and Maja Främme, students of the International Logistics programme at the Chalmers University of Technology. The theory constitutes fifteen academic credits out of a total of 180 credits. The topic of global trade with shipping containers is and will continue to be a hot topic. This study aims to identify and describe the potential occurrence of different chemical compounds in shipping containers and the necessary measures to prevent and mitigate the risk of occupational health accidents among people working close to the shipping containers.

We want to thank and thank Dr. Lundeberg, Danderyds Sjukhus, Sweden, for giving us insights about our research questions. We also thank Dr. Kent Salo, who acted as supervisor and provided helpful and valuable guidance and feedback throughout the report. Additionally, we would like to extend our gratitude to Gasmeststation Nederland B.V., who provided us with valuable data and insights on the operations concerning container gas measurements.

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SAMMANDRAG

Ungefär 30% av världens fraktcontainrar som dagligen transporteras kan innehålla vissa förhöjda koncentrationer av olika kemikalier som kan ha sitt ursprung i bekämpning av skadedjur eller emitteras av lasten. Studien fokuserar bara på containrar som transporteras på havet, luftburna kemikalier samt belyser flyktiga organiska föreningar.

Studien undersöker om kemikalierna kan uppstå från fumigation och naturlig avgasning av kemikalier från det paketerade godset som fraktas. Denna studie identifierar, kategoriserar och jämför litterär förekomst av kemikalier och faktiska mätningar från ett företag som gör det dagligen. Denna studie ville undersöka om gaser kan släppas ut under transport på långa sjöresor eller om det bara är från fumigation kemikalierna uppstår. Resultaten visar en högre volym av kemiska gaser i fraktcontainrar och att de flesta emitteras med största sannolikhet under transporten. Detta indikerar att väsentligt fler fraktcontainrar, än de som är etiketterade, kan innehålla en mix av kemikalier beroende på transporten och typ av gods som transporterats.

Nyckelord: Fumiganter, arbetsmiljö, farliga gaser, fraktcontainer, logistik, kemiska ämnen, toxikologi, mätningar

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ABSTRACT

Approximately 30% of all the worlds shipping containers that are transported daily may contain increased concentrations of different chemical compounds that may be toxic and carcinogenic. The study focuses only on containers transported by sea and airborne chemicals and highlights volatile organic compounds.

This study investigates the correlation between fumigation and natural off-gassing chemicals from the packaged goods shipped. The study identifies, categorises, and compares literary appearances from chemicals and measurements from a company performing container gas measurements daily. This study wanted to investigate if gases can emit during transportation on long sea voyages or if it is just from fumigation these chemicals originate from. The results show a higher volume of chemical gases inside shipping containers and that most chemical substances in shipping containers are most likely emitted during transportation. This indicates that significantly more shipping containers may have a mixture of chemicals depending on the transportation and type of goods transported.

Keywords: Fumigants, occupational safety, toxic gases, shipping container, logistics, chemical compounds, toxicology, gas measurement

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ACRONYMS AND TERMINOLOGY

CTU	Container Transport Unit
ECHA	European Chemical Agency
FEU	Forty-Foot-Equivalent-Unit
FTIR	Fourier Transform Infrared Spectroscopy
GC-MS	Gas Chromatography-Mass Spectrometry
HAZARDOUS	Substances that may be toxic and cause harm
HPLC	High-Performance Liquid Chromatography
ISO	The International Organization for Standardization
LCL	Less Container Load
OEL	Dutch 8-h occupational exposure limit
PID	Photoionisation detector
PPB	Parts per billion
PPM	Parts per million
RAGS	Remote Activated Grab Sampler
RIVM	Rijksinstituut voor Volksgezondheid en Milieu (National Institute for Public Health and the Environment)
SIFT-MS	Selected-Ion Flow-Tube Mass Spectrometry
STEL	Short-term exposure limit
TEU	Twenty-foot Equivalent Unit
TLV	Threshold limit value
UN	United Nations
UV	Ultraviolet
VOC	Volatile Organic Compounds
VROM	The Dutch Ministry of Housing, Spatial Planning, and the Environment

1. INTRODUCTION

Global world trade is derived from the supply and demand of goods and services. Today's transportation of goods is necessary, and international trade plays a significant role in the world economy. Shipping is central to the economy, and today it links the supply of goods and the demand for products from consumers worldwide (Frankel, 1989; UN, 2016). The use of the container, an invention that dates to the 1950s, is an important development in the transportation industry (Levinson, 2006). Shipping containers have revolutionised and transformed how goods are transported, providing a standardised and efficient method for packing, transporting, and unloading. The increased use of standardised cargo transportation has contributed to the growth of maritime trade. Ships carry 80% of the global trade volume, and the world container throughput in 2020 was estimated to handle volumes of up to 815.6 million containers, as reported by the United Nations (2021).

The increased use of container shipping for general cargo has brought challenges. One of these is the need to fumigate the container with consumer goods to reduce the invasive species and diseases that can cause damage to crops, ecosystems, and human health (IMO, 2008; Preisser et al., 2012). The fumigation process involves exposing the contents of a container to toxic gas, such as methyl bromide or phosphine (Svedberg & Johanson, 2013). The use of methyl bromide, also known as bromoethane, has been banned in the United States (US EPA, 2023) and the EU since 2010 (PHE, 2019), resulting in a mixture of different industrial chemicals being used as fumigants today in shipping.

Fumigation has become standard practice in the shipping industry, ensuring the safety and quality of the goods transported. In a global and complex transportation network, goods are transported multimodal in a non-ventilated controlled environment. Research has addressed that fumigants derived from the fumigation process can be present in shipping containers (Bauer et al., 2009). The fumigation used for the process can be toxic and dangerous to human health and safety, resulting in the potential that the container constitutes an occupational health risk for people working inside or exposed to containers (Svedberg & Johanson, 2013).

Containers fumigated in previous transportation can contain residual amounts of toxic gases that can accumulate in a shipping container (von Eichhorn, 2020). This highlights the risk that even residual amounts of fumigants or even the goods themselves can emit gases resulting in the need for proper ventilation and measuring of these gases that can help to protect the health and safety of workers in the shipping industry, as some gases may not have distinct warning characteristics. The reuse of shipping containers by multiple parties and stakeholders with different modes of transportation makes it crucial to have accurate information about the container's contents and if the containers have been fumigated. This emphasises the need for proper procedures to reduce exposure to these toxic gases (Svedberg & Johanson, 2013).

In the Port of Rotterdam, between the deep-sea terminals, a company called Gasmeetstation Nederland B.V., performs container gas measurements daily of shipping containers unloaded in the port from long sea voyages. The company perform gas measurements in the hinterland terminals, customer locations or through their drive-in facility in Maasvlaakte, Rotterdam (Gasmeetstation Nederland B.V., n.d.). This service is offered among other logistics activities in the port. The company also provides forced ventilation of shipping containers if the measurement is declared to have elevated levels above critical exposure limits that oppose an occupational health risk.

The correlation between toxic gases inside shipping containers and their origin is a critical issue that requires further research and exploration with reproducible data. The occurrence of these toxic gases has important implications for human health. There needs to be a standardised method of measuring these gases to help identify toxic chemical gases and their origin. Understanding current research would improve the overall knowledge regarding the harmful impact of gases in containers on humans and health.

1.1 Aim of Study

The report aims to identify what toxic chemical gases may be present in shipping containers and the origin of these. The study also aims to understand how these gases can be identified and if any procedures can reduce the risks of exposure.

1.2 Research Questions

1. Under what circumstances is the presence of toxic chemical gases in containers during transportation most likely to occur?
2. How can these toxic compounds be measured, identified, and categorised?

1.3 Delimitations

1. The scope of the research is limited to shipping containers used for transporting packaged goods.
2. The study will only focus on containers transported by sea.
3. The study will only focus on data from the Port of Rotterdam compared to data from the literature review.
4. The study only focuses on the shipping container, i.e., the ISO container.
5. The study will focus on airborne chemicals and highlight volatile organic compounds (VOC) in a shipping container.

2. THEORY

The theory related to the subject will, provide a deeper understanding of the topic in this study section. Earlier literature will be reviewed.

2.1 Airborne Chemicals in Shipping Containers

Airborne chemicals in containers consist of inorganic compounds, i.e., hydrogen cyanide and VOCs. VOCs are organic chemical compounds that can be emitted from different solids or liquids (US EPA, 2023). VOCs have the ability to be present in the atmosphere inside a shipping container, as the gases can be emitted from materials. Different airborne chemicals have different structures and may have different abilities, such as having adverse health effects, i.e., being toxic or carcinogenic. VOCs indoors have higher concentration levels than outdoors (US EPA, 2023).

2.2 Sources of Airborne Chemicals

The concerns about shipping containers' toxic chemical gases have generated several research studies highlighting fumigants as a direct problem to occupational safety working with containers. There are several guidelines on how to treat potentially dangerous import shipping containers. For example, the Netherlands have adopted and incorporated guidelines and national legislation regarding the safe handling of containers. Most of the import containers arriving in Europe are not opened in ports but might still be opened by the end-user in the supply chain (Bråtveit et al., 2018). Goods and their material can also release chemical gases, which can have different unfavourable health effects (Lovas et al., 2022; Matsukawa et al., 2015; Budnik et al., 2017). The uncertainty and risk assessment of chemicals in shipping containers may differ and increase if there is an unawareness about the factors that enable chemicals to be present.

2.2.1 Fumigation

Fumigation is described in The International Maritime Dangerous Goods (IMDG) Code (IMO, 2006). Fumigation is a pest control method where industrial chemicals such as phosphine, hydrogen cyanide, methyl bromide, chloropicrin or sulphuryl fluoride can be used (Svedberg & Johanson, 2013). Different types of cargo may require different types of fumigants for effective pest control (van Someren Graver, 2004). The process of fumigation may be mandatory to prevent invasive species and microbiological spread in a freight container with packaged goods (IMO, 2010). The container must be sealed to enable an effective fumigation process so that the gas does not leak during transportation (Banks et al., 1986; Coetzee et al., 2020).

Fumigants can oppose an occupational health threat for people loading, unloading, or opening a shipping container or other confined spaces. At the end of the supply chain, container receivers may also be at risk of exposure (Baur, 2015). Chapter 5.5.1.3.1 in the IMDG Code from the International Maritime Organization (IMO) states that fumigated containers shall have the correct warning stickers or labelling if the container has been fumigated (UNECE, 2006). Fumigation can also be conducted in-transit locations and is then regulated by the provisions of the IMDG Code as FUMIGATED UNIT CLASS 9 UN3359 (UNECE, 2006; Gafta, 2018). According to the IMDG code, fumigation is considered dangerous cargo. Therefore, the

container shall follow relevant legislation related to the fumigation provisions, as fumigation can be conducted before the destination and in transit. Fumigation of shipping containers can not be carried out during transportation unless authorised. The shipping container shall also have the correct documentation with the proper warning sticker with details of the fumigant used, the amount and the date and time when the container was fumigated (UNECE, 2006).

2.2.2 Packaging Material

How packaged goods inside a container are stowed may depend on the type of goods transported or if it is stowed in a Twenty-foot Equivalent Unit (TEU) or Forty-Foot-Equivalent-Unit (FEU). Different cargoes have different stowing needs because of volume, shape, weight, and density differences. Therefore, there are different ways to load a shipping container depending on the goods or volumes transported. How cargo is loaded and stowed inside a container can result in shipping containers having a variance in the filling degree and what types of goods are being transported during a voyage. Different packaging materials used for the cargo can be different types of wood pallets, carton boxes made from plastic or paper wrapped with different dunnage materials for protection and other materials from the manufacturer of the products (British Columbia, 2016).

2.2.3 Cargo

Some general cargo that can be packaged and shipped in a container can be different consumer goods, i.e., foodstuffs, white goods, electronics, clothing, footwear, textiles, pharmaceutical, toiletries, drugs, oils and chemicals, fertilisers, paints, machinery among other general cargo (Neylan, Poore & Foxcroft, 2018).

How the package is stowed, and which packaging materials are used depends on the type of commodity being transported. The purpose of logistics is the way to consolidate cargo correctly – as the volumes being transported directly influence the cost of the transportation. The most optimal is to have a high filling degree percentage of goods stowed in the container. There could be a combination of packaged goods in a container, depending on the type of transportation. In Less than Container Load (LCL), a mixture of types of goods can be shipped in the same container meaning that the packaged goods for several importers may be transported in the same container (C Land Logistics, 2022).

2.3 Toxicology Effects

Exposure to different chemicals has led to the awareness that occupational exposure close to shipping containers may have adverse health effects on humans (Bauer et al., 2015). Some chemicals are natural, and some are manufactured, which can have harmful and toxic effects. The United States Environmental Protection Agency (US EPA) describes that most fumigants are industrial solvents and human-made (US EPA, 2023). Long-time exposure to shipping containers having chemical gases inside may cause chronic adverse effects that can increase the risk of intoxication and cancer (European Commission, 2020). Different chemicals have different toxicity, such as ethylene dichloride, methyl bromide, phosphine, and methylene chloride, that can cause various symptoms, such as nausea and respiratory irritation (Preisser et al., 2012). Different VOCs can affect respiratory symptoms, and exposure can have different correlations to health effects leading to increased mortality (Yoon et al.). There has been reported that workers working with container loading have been acutely poisoned (Preisser et al., 2012, 2012; Kloth et al., 2014; Baur et al., 2015; (Bråtveit et al., 2018). Exposure to

extended periods of fumigants can also have adverse toxicological effects (Verschoor et al., 2012).

2.4 Concentration Levels and Occupational Exposure Limits

Substances that are classified as carcinogenic, mutagenic and reprotoxic (CMR) may have different exposure limits (European Agency for Safety and Health at Work, 2022). Exposure to chemicals labelled as CMR should be avoided (Linköping University, 2023). Chemicals being named CMR can be explained by their chemical abilities, but also by the European Chemicals Agency (ECHA) and how they give opinions on the toxicity of the exposure limits based on the Directive (2004/37/EC) and in the Directive (98/24/EC) on occupational health and safety exposure (ECHA, 2023).

The exposure limits are different but measured in small concentrations, i.e., in parts per million (ppm) or parts per billion (ppb) levels. The occupational exposure limits can be set as the threshold limit value (TLV) or occupational exposure limit (OEL) levels that either describe the general threshold limit of exposure or the daily limits of exposure, that is, the eight-hour exposure limits, e.g., the minimum levels of exposure to not get intoxicated after eight hours. The concentration limits may differ between countries and are regulated by regulatory authorities (ECHA, n.d.).

Directive 98/24/EC (2021) regulates the European Union (EU) concentration limit values, and Directive 2004/37/EC on occupational exposure to carcinogenic and mutagenic chemicals (ILO, 2011). For acute exposure, another exposure limit called the short-term exposure limit (STEL) regulates occupational exposure for just a few minutes (George Wypych, 2014; ILO, 2011). Analytical techniques enable the identification and detection of toxic chemicals but have different capabilities for detecting concentration levels. Measuring containers is a risk assessment where it is possible to screen containers and potentially reduce the occupational risk of exposure to concentrations above the exposure limits. Other chemicals have different TLV values and are set by the American Conference of Governmental Industrial Hygienists (ILO, n.d.).

2.5 Relevant Regulations for Gas Analysis in Enclosed Spaces

In 2007, the EU adopted a new regulation for the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH) to increase safety and health against chemical exposure risks (European Chemicals Agency, n.d.). The regulation is a framework for all chemicals. However, it does not regulate the occurrence of chemicals inside shipping containers, as the regulation regulates the manufacturing and safe use of chemicals. The REACH regulation serves as a framework for incentives, directives, and other national legislations in the EU for chemicals.

Several EU directives have highlighted the need for safe container handling and inspections. The international conventions can be adopted by national law. Unfortunately, gas measurements in enclosed spaces are not standard in most countries due to a lack of incorporation of the directives, legal framework and incentives. Extensive guidance on the secure application of fumigated cargo transport units such as shipping containers has been made available through the IMO (IMO, 2008). The United Nations (UN) IMO Safety of Life at Sea (SOLAS) Convention controls the majority of relevant regulations, codes, practices and recommendations for shipping containers at sea. Meanwhile, Occupational Safety and Health

Convention 155 (ILO) have highlighted several directives on the practice of safety and health in ports (Bråtveit et al., 2018).

The potentially hazardous environment inside shipping containers has resulted in various recommendations and incentives. The Netherlands is one country where gas measurements on shipping containers are performed daily. Different recommendations, directives and national legislations are relevant for gas analysis in enclosed spaces. The Dutch Ministry of Housing, Spatial Planning and the Environment (VROM) in the Netherlands commissioned the Dutch National Institute for Public Health and the Environment (RIVM) to study the presence of gases in import containers (RIVM, 2003). Gas analysts must inspect enclosed spaces before entering, as the Working Conditions Decree in Article 3.5g (Overheid, 2023) regulates it in the Netherlands. Shipping containers have no natural ventilation or system that enables natural ventilation since the container is sealed during transportation (Svedberg & Johanson, 2017).

The Working Conditions Decree forces employees and employers to combat occupational risks, and an enclosed space that is suspected of containing a mixture of substances to a great extent can only be entered after investigation; in this matter, a container gas measurement will show that the container may not be hazardous to enter (P.J. Hahurij, personal communication, March 16, 2023). This highlights that container gas measurements are conducted as a standard procedure in the Netherlands based on this law.

2.6 Reused Containers in the Supply Chain

Different users in the supply chain can use containers (Shipping & Freight Resource, n.d.). The containers can be leased or owned. In the event of a leased container, it may be returned to the leasing entity upon reaching its destination (Lumetzberger, 2010). If a container has undergone fumigation during its previous transportation, it can result in safety risks and incidental exposure if no appropriate documentation is supplied (Bauer et al., 2010).

Container ownership is interchanging and needs to meet different transportation requirements. This can result in the risk that the container has been fumigated in previous transportation. This was when a man in the Port of Hamburg opened a container with consumer goods and got intoxicated by exposure to fumigants. The cargo of the consumer goods had not been fumigated, but the previous cargo transported in the same container had been (von Eichhorn, 2020). Therefore, residual trace amounts of fumigants and other toxic chemicals may remain in the shipping container.

2.7 Container Gas Measurements and Ventilation

Gas measurement is a chemical analysis that aims to determine the concentrations of a gas mixture inside an enclosed space, i.e., the shipping container. Using different techniques will result in differences in the capabilities of quantitative and qualitative analysis (Lagesson-Andrasko et al., 1998). To identify and reduce the risk of hazardous exposure, performing a container gas measurement enables the identification and detection of chemical gases. Ventilation of the containers can reduce the fumigants and the off-gassed airborne chemicals present in the container (Hinz et al., 2021). The shipping containers do not enable natural ventilation since the container is sealed during transportation. Containers' ventilation can result from opening a container door or performing ventilation (Braconnier & Keller, 2015). Recently a new method for ventilation of containers has been studied to reduce the toxic concentrations of airborne chemicals inside shipping containers (Svedberg & Johanson, 2020).



Figure 1. Own photograph. Example of how the gas inside a shipping container can be extracted using a metal probe as the sampling method, inserting the probe in between the container wall and container door, and penetrating the rubber seal.

2.7.1 How to Perform a Container Gas Measurement

To be able to measure the concentrations of chemicals present in a shipping container, there is a need to perform a sample extraction, as seen in *Figure 1*. Different sampling methods can differ depending on the measuring technology used to perform appropriate gas extraction inside

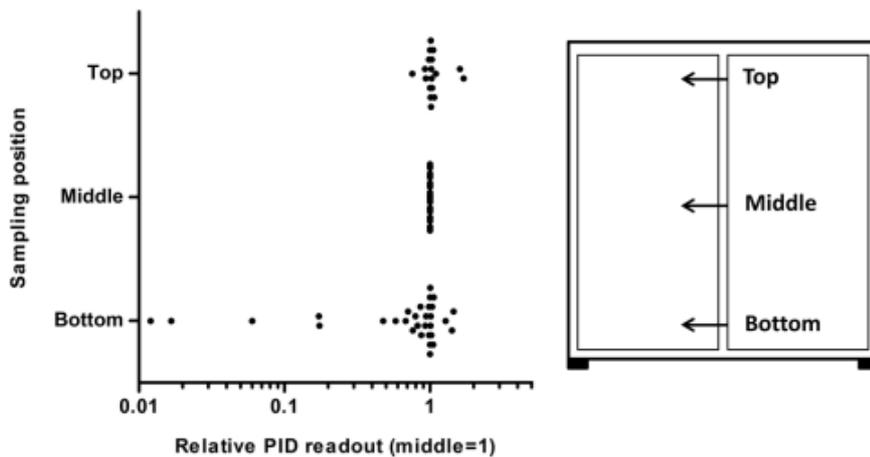


Figure 2. Illustration of readouts in different sampling positions (Svedberg & Johanson, 2017).

the shipping container. Sampling is crucial for successful chemical analysis (Sargazi et al., 2021). The gas is then extracted with the sampling method that fits the measuring equipment. One sampling method is performed by penetrating the rubber, as seen in *Figure 1*. This sampling is performed the same, not limited to the container size. Before a container gas measurement, a sampling method must be chosen depending on the measuring equipment used, as this procedure may differ depending on technologies. The sampling method and the process of penetrating the rubber list may vary in degrees of precision and result if the sampling position differs between the measurements (Johanson & Svedberg, 2020).

This standardised sampling method may vary in precision as the same spot is only measured. Different sampling positions are illustrated in *Figure 2*. The fulfilling degree may result in different concentration levels of chemicals. After inserting the probe, a measurement is conducted. The result is then whether the container is safe to enter. The container gas measurement is a risk assessment method and inspection, enabling an understanding of whether an enclosed space is safe to enter. Sampling from the bottom of the container could show lower concentrations of chemicals (Svedberg & Johanson, 2017). However, there is also a risk that the floor in a container could emit chemical gases (Svedberg & Johanson, 2017) or that chemicals can be found at a floor level that is heavier than air (Knol-de Vos, 2002).

3. METHODS

The study employed a qualitative literature research method summarising existing research on the subject. The study also collected data from qualitative interviews.

3.1 Design of Method

The literature review, a meta-analysis, was used to analyse and gather existing research to understand the topic better. The literature review involves organising and critically examining chosen literature. The reason for using this method was to understand better the airborne chemicals present in shipping containers and their impact on humans and health and to increase awareness of fumigation and fumigants.

The interviews were qualitative and performed using a semi-structured format. Qualitative interviews were conducted to gain a better understanding of the correlation between the occurrence of chemical gases and their origin by interviewing a well-known company in the Port of Rotterdam conducting daily container measurements of shipping containers. This would give evidence from daily measurements that could be compared to the literature appearance parallel to the literature research. A semi-structured interview allows a deep understanding and the possibility of coming to multilayered conclusions (Kalika, 2021). The type of interview also gave the possibility to follow up on most questions. Kalika (2021) further mentions that with a semi-structured interview, follow-up questions can be posed with verbal replies and non-verbal such as silence, laughter, or a sigh.

3.2 Procedure

This study's approach to a scientific literature review consists of seven steps that Fink (2019) proposed. The first step was to formulate the research questions for the subject, followed by conducting the data collection from various sources such as bibliographic databases, websites, and articles. Next, the third step was searching for relevant keywords and terms related to the research question. After that, the literature needed to meet specific screening criteria, including language, article type and publication date that supports the data collection of the research question but also follows the limitations of the topic and includes scientific quality of the literature using specific methodological criteria. Later the literature picked was reviewed, and then the literature was synthesised and interpreted in conclusions.

3.3 Data Collection

The data collection combined primary and secondary resources to support the study further and aimed to summarise what was known within the selected topic by conducting literature research together with qualitative interviews. This methodology would provide the report with several data sources for relevant conclusions answering the research questions. The combination of data would also give reliable analyses of existing research and provide added information and data on the subject.

Data given from Kevin Schwartz at Gasmeetstation Nederland B.V. were used to compare actual number of detected compounds in the literature versus real-time data gathered over several years of container gas measurements. The list of substances in the *Appendix* that has

some form of correlation to application uses, or containers have been used in this study and in the figures to increase awareness of the substances and compare them against relevant research.

3.4 Qualitative Interviews

With purposive sampling, specifically expert sampling (Hassan, 2022), the interviews became more in-depth understanding. They added information, allowing for greater predictability and reliable information about the typical scenarios behind the presence of chemical gases present in containers. The choice of understanding the correlation between variables, cause, and effect was driven by obtaining qualitative data collection, as presented by Patel and Davidson (2019). Therefore, the interviews served as qualitative data collection and were compared to the literature on this subject. The qualitative interviews were conducted to have better answers to the following questions:

Table 1. Questions for interviews.

Questions
Why is one company performing container gas measurements?
What were the driving forces to enable this service for clients?
Who is the buyer of the service of the measurements?
How many containers that are measured are fumigated containers, and which are not?
Are more containers which are rejected originating from the fumigation process?
Do container carriers know about the problem with chemicals present in shipping containers?
Why is there a need for more knowledge, and can container gas measurements be implemented in other countries?
Would container gas measurements be an incentive to increase the value-added service for container carriers in their hinterland operations?
What is the procedure for the container gas measurements? How does it affect the supply chain?

The respondents were Kevin Schwartz, a terminal manager at Gasmeststation Nederland B. V., located in the Port of Rotterdam. He has been working since 2011 with container gas measurements and provided not only information about their work but also the data in *Appendix*. The second respondent were Peter Hägg, Operations director at MSC Mediterranean Shipping Company, that has experience and knowledge about maritime shipping and container transportation.

3.5 Literature Search

A list of specific search terms was identified from the two research questions and the topic of this study. These keywords and databases are described in *Table 2*.

Table 2. Identified search terms relevant to the subject and research questions.

Keywords	Database	Hits
container, freight, gassing	Scopus	4
container, fumigants, chemicals, Sweden	Scopus	2
container, fumigants, risk	Scopus	29
container, fumigants, residuals	Scopus	14
shipping, container, history, economy, containerisation	Scopus	3
security, containers, practical, terminal	Scopus	8
fumigation av fraktcontainrar (in Swedish)	Google Scholar	3

Relevant articles were found with the help of Google Scholar, ResearchGate and Chalmers library databases with keywords mentioned in *Table 2*. The articles are limited to those published between 2005 and 2022 to provide new and actual information supporting the study’s introduction. The information about containerisation and relevant scientific studies about toxic gases inside containers is presented from materials within the same period.

3.5.1 Extending the Literature Search

A more specific search was conducted, as seen in *Table 3*, using “” to identify relevant search results.

Table 3. *Extending the literature search for relevant publications.*

First word	Conjunction	Second word	Hits on database
Gas measurements	and	Shipping container	58 000, Google Scholar

Previous studies on the subject had several references from the same studies, meaning snowballing was used in addition to extending the literature search. Snowballing means that relevant references in the reviewed literature can be used and added to the search as an alternative to expand the literature search (Choong et al., 2014).

4. RESULTS

The results presented in this chapter are based on the literature review and the data collection from the qualitative interviews using the semi-structured approach. The results obtained are from questions found in *Table 1*.

4.1 Under What Circumstances Do Chemical Gases Occur

From the data collection obtained in this study, the comparison showed that only nine chemicals correlated to being a fumigant, meaning that only 2,71 % of all 332 chemicals found in shipping containers are fumigants. The rest is chemical compounds most likely correlated to the general cargo or the packaging materials. Recent literature research has been limited to the correlation of chemical gaseous inside shipping containers to fumigation and has been highlighting fumigants and industrial gases as the prior generator of chemicals present in shipping containers (Bauer et al., 2010; de Groot, 2007; Frost, 2010; Hinz et al., 2021; Knol-de Vos, 2002; Luyts & Mück, 2011; Mück & Stock, 2012; Svedberg & Johanson, 2017; Tortarolo, 2011; Wagstaffe et al., 2012).

4.1.1 Fumigation

Most of the studies presented in this study have been experimental, focusing on the gaseous pesticides or residual fumigants of known industrial chemicals. Containers with consumer goods such as shoes, furniture, foodstuffs, electrical components, manufactured goods, natural products, and textiles had elevated concentration levels of chemical substances (Bauer et al., 2010). Fumigation is a contributing factor that some airborne chemicals are present in shipping containers. Fumigants can not be a factor that chemical gases occur during transportation since it is performed before the transportation.

4.1.2 Humidity, Air Pressure and Temperature

Temperature, air pressure and materials can affect that gases are emitted during transportation. The comparison of the literary appearances versus the chemical compounds that Gasmeststation Nederland B.V. has correlated identifies that gases are most likely to be emitted during transportation due to air pressure, temperature, and humidity. A study confirmed that gases might increase in concentrations if analysed with higher ambient temperature (Johanson & Svedberg, 2020). The measuring equipment used for the analysis may differ in how good their abilities for quantitative and qualitative analysis are. Cargo can be affected by outside temperature as well as the feasibility to adsorb humidity. Cargo can also be affected by condensation, and the cargo can emit humidity. Further, the inside temperature of a container can increase as it is affected by the outside temperature (Hapag-Lloyd, 2005).

4.1.3 Materials and Goods

The result also shows that plastic commodities, including plastic packaging material, correlate to the presence of airborne chemicals and VOCs (K. Schwartz, personal communication, March 1, 2023). For example, the report by Budnik et al. (2017) further mentions that chemicals such as phosphine, methyl bromide and ethylene were described in an experiment to see how packaging material and clothing adsorbed and released amounts of gases. The literature shows that consumer goods can adsorb different pesticides derived from fumigation to be later released

from the consumer goods (Knol et al., 2005), which can result in different containers being more hazardous than others depending on the goods or packaging.

4.2 Factors that Affect the Measurements

The concentration levels of the chemicals in shipping containers may differ when the measurement is performed. Ambient temperatures of +12 °C to +15 °C are the optimal weather conditions for gas measurements (K. Schwartz, personal communication, March 1, 2023). Depending on the time of the day the gas measurement is performed, the temperature will affect the analysis because the chemicals will tend to stick to the container wall during colder days (K. Schwartz, personal communication, March 1, 2023), as they can condensate changing the aggregation phase from gas to liquid phase. This changes depending on the chemical structure of each chemical and its tendency to be volatile. Chemical compounds with different chemical structures and capabilities, such as melting or boiling points, affect the gas measurement outcome (K. Schwartz, personal communication, March 1, 2023).

4.3 Peer-Reviewed Studies

This study found three peer-reviewed publications relevant to fumigation and containers; then, several reports are produced by institutions or others on the same subject. The first peer-reviewed publication was a study on 2,113 containers in the Port of Hamburg in 2006. The study used a combination of technologies for sampling and measuring the gas mixture. Tedlar® Bags performed sampling extraction of the gas. For the chemical analysis, Selected-Ion Flow-Tube Mass Spectrometry (SIFT-MS) and the other analytical technique, Gas Chromatography-Mass Spectrometry (GC-MS), were used. The study confirmed that 1478 containers had toxic chemicals above chronic reference exposure levels, which was 70% of all the containers in the study, indicating a majority that had increased levels. The study also confirmed that only 3,6% of the total volume of containers in the study had correct documentation according to the IMDG code (Bauer et al., 2010). Most measured containers (56,9%) came from China, Asia (Bauer et al., 2010).

The second peer-reviewed publication found in this study was a study based on two earlier experiments conducted in 2010 and 2013 by Svedberg and Johanson (2017). The two authors included an earlier pilot study from the Port of Gothenburg. A total of 249 containers were included in the study. These containers were measured with several techniques such as photoionisation detector (PID), Fourier-transform infrared spectroscopy (FTIR) and GC-MS using Tedlar® Bags for the analysis with the GC-MS. Using the FTIR, the study found that thirty containers had fumigants off-gassing from the goods in concentrations above OEL. The authors also discovered increased levels from the floor of the containers. Further, they described different measuring equipment and compared their abilities to measure other gases.

A more recent study in New Zealand led by Ruth Hinz et al. (2021) was peer-reviewed by Gunnar Johansson, one of the other authors of the previous peer-reviewed study. The study investigated 490 sealed containers, resulting in their findings that fumigants were found in 11,4% of the containers. The study also found that some cargo types from China had significant concentrations of fumigants and other airborne chemicals. SIFT-MS was used for the measurement, and the sample extraction with Tedlar® Bags was used together with a probe. PID detection technology was also used for comparison testing in the study.

4.4 National Incentives in the Netherlands

In 2002 the National Institute for Public Health and the Environment (RIVM) studied 303 containers. The study concluded that 21% of the containers had a presence of gaseous pesticides (chemical compounds) derived from fumigation. The study also determined that only 0,99% of containers had the correct mandatory warning stickers after fumigation (Knol-de Vos, 2002).

A probe was used to penetrate the container seal then the air was collected using Tedlar® bags. A GC-MS instrumentation then performed the analysis. A specific electrochemical cell was also used for phosphine detection. The analytical techniques HPLC with UV detection were used to determine the cartridges, also used in the study. The study claims with 95% certainty that a high percentage of import containers in Rotterdam will have higher concentrations of airborne chemicals that oppose a health risk (Knol-de Vos, 2002).

4.5 Variance in the Results of Concentrations Above Exposure Limits

In a report from 2007 from RIVM, a trend analysis between 2003 and 2006 from 277 containers determined variance in the presence of fumigants in shipping containers between different years (de Groot, 2007). There was a variance in the concentration levels' findings and what substances were detected. The report also categorised the substances that were not mentioned as known to be correlated to fumigation, correlated to glues, paints, varnishes, and plastics, among other commodities.

Between 2007 and 2008 in Australia, 14,943 containers were tested, and 2,503 had fumigants above OEL (17%), using SIFT-MS and Dräger handheld sensors together with Tedlar® bags (Frost, 2010). Another study in 2011, also in Australia, measured 76 containers with SIFT-MS originating from China, Asia. The study determined that 47 of the 76 containers had some residual chemicals present, and eight percent had limits above OEL (Prezant, 2012).

Italy has actively been conducting inspections of containers since 2004. At the publication date, 9,482 containers had been inspected during the active years of inspections, and (20%) had residual concentrations of fumigants inside (Tortarolo, 2011). In another study between 2010-2014, 2,027 containers were analysed in the Port of Hamburg with TD-GC/MSD and TD-2D-GC-MS/FPD using Tedlar® bags (Budnik et al., 2017). The results showed that different chemicals exceeded OEL, e.g., toluene residues in 90% of all containers.

4.6 Concentrations Above Exposure Limits

In 2011, a report was made analysing 42,888 containers in the Netherlands and Belgium. Ten percent of the containers were measured and tested at the end-user location, and the rest were tested and measured in the port. SIFT-MS was used as the analytical instrumentation. The results concluded and determined that 4,929 containers (11%) had concentrations of toxic chemicals above OEL, and the origin of containers that had the most toxic concentrations had their origin of destination from Southeast Asia (Luyts & Mück, 2011). A study of 123,349 containers was measured in the same year with a broader geographical reach in Austria, Belgium, Denmark, Germany, the Netherlands, and Spain with SIFT-MS, colourimetric tubes and PID. The result concluded that 13% of all the containers had concentrations above OEL. The extensive study also identified that fumigated containers from Asia were not commonly labelled as being fumigated (Mück & Stock, 2012). The study also tried categorising a correlation between consumer goods and the occurrence and presence of chemicals.

Table 4. Relevant studies for gas measurements on containers with different sample methods, measuring equipment for different years, and the percentage of airborne chemicals found.

Experiments	Location	Year	Containers	Sample extraction	Measuring equipment	Chemicals present above OEL
(Knol-de Vos, 2002)	Rotterdam	2002	303	DNPH cartridges, Tedlar®	Electrochemical cell, HPLC & GC-MS	21%
(de Groot, 2007)	The Netherlands	2003–2006	277	n/a	n/a	Up to 60%
(Tortarolo, 2011)	Italy	2004–2010	9,482	n/a	Electrochemical sensor, catalytical sensor & PID	40%
(Bauer et. al., 2010)	Hamburg	2006	2,113	Tedlar®	SIFT-MS, GC-MS	70%
(Frost, 2010)	Australia	2007–2008	14,943	Tedlar®	SIFT-MS, Dräger	17%
(Wagstaffe et. al., 2012)	Australia	2012	76	DNPH cartridges, Tedlar®, RAGS	SIFT-MS, PID, GC-MS	97,4%
(Mück & Stock, 2012)	Belgium, Netherlands	2010	123,439	n/a	SIFT-MS, PID, Colorimetric tubes	13%
(Luyts & Mück, 2011)	Europe	2010	42,888	n/a	SIFT-MS, PID, Sensors, Colorimetric tubes	11%
(Budnik et al., 2017)	Hamburg	2010–2014	2,027	Tubular steel lance, Tedlar®	TD-2D-GC-MS/FPD, TD-GC/MS	Up to 90%
(Svedberg & Johanson, 2017)	Sweden	2013	249	Tedlar®	FTIR, GC-MS	12%
(Hinz et al., 2021)	New Zealand	2021	490	Teflon tube, Tedlar®	SIFT-MS, PID	11,4%

4.7 Detection Capabilities of Different Measuring Equipment

In 2017, a Swedish research study highlighted that the concentration levels found in their study could be described by the poor detection limits of the FTIR and that the choice of analytical instrumentation must be chosen by the specific location conditions (Svedberg & Johanson, 2017). The authors further describe that GC-MS offers in-depth detailed information about chemicals and that an FTIR analysis may have higher specificity and sensitivity than PID detectors. The authors also describe an FTIR to be faster than a GC-MS. Different measuring equipment has different abilities to perform a chemical measurement but is an essential tool for different applications. The variance in the results clearly shows that the analysis may differ in method and performance and that some instruments are better designed to either detect specific substances or made to be used for a wide range of analyses performing non-targeted analysis. Non-targeted analysis means that a chemical analysis aims to identify as many chemicals present in a sample (Chromatography Today, 2022).

Table 5. Different capabilities of different analytical methods. General overview of the comparison between the methods in Table 4.

	HPLC	GC-MS	SIFT-MS	PID	FTIR	Sensors	Tubes
Advantages	Analyte types ¹	Volatiles and semi-volatiles ³	Hydrocarbons and VOCS ⁵	Handheld ⁶	Speed ⁸	Analytes ¹⁰	Speed ¹²
Disadvantages	Cost ²	Selectivity ⁴	Limited ⁶	Accuracy ⁷	Sensitivity ⁹	Limited ¹¹	Color ¹³
Main Setting	Lab	Lab	Field	Field	Field	Field	Field
Chromatograph	Yes	Yes	No	No	No	No	No
Substance	Several	Several	Several	Specific	Specific	Specific	Specific

(Timchenko, 2021^{1,2}; Moore Analytical, n.d.³; WhatIsHPLC, 2023⁴; Choi et. al, 2022⁵; ION Science n.d.⁶; Kroes, 2016⁷; Thermo Fisher Scientific, 2015⁸; Svedberg & Johanson, 2017⁹; Ohashi & Dai, 2006¹⁰; National Research Council, 1995¹¹; Homeland Security, 2008^{12,13})

In all the studies, different measuring equipment has been used, as seen in Table 4. They all have different capabilities in their ability for chemical analysis. PID is a photoionisation detector that enables a UV photon to be absorbed by a molecule. It is a simple detector which can be handheld. PID can measure many VOCs but be limited to the detection of other gases like carbon dioxide, carbon monoxides, sulphur dioxides, methane, ethane etc. (ION Science, n.d.) The definition of analytical instruments and detectors may have different legal definitions depending on their use or abilities. FTIR is a Fourier-transform infrared spectroscopy method (RISE, n.d.). A sample absorbs infrared radiation, which causes molecules to vibrate at specific frequencies that enable an analysis. FTIR is a fast analysis method but has limitations for complex mixtures of gases (Knol, 2007).

The technology of SIFT-MS applies chemical ionisation reactions to detect VOCs and inorganic gases (Syft Technologies, 2013). GC-MS is regarded as the gold standard in analytical chemistry to determine molecules' molecular weight and structures (Turner, 2022). Gas chromatography is a technique where a mixture of compounds can be separated (Hopfer, 2020). Together with a detector or spectrometry approach, a hyphenated technique enables both quantitative and qualitative analysis. Analysis of functional groups and classification of unknown compounds can differ (Nilsson et al., 2005; Lagesson-Andrasko et al., 1998). High-performance liquid chromatography (HPLC) is an analytical instrumentation often used with a UV detector to analyse trace amounts of unknown chemical compounds (Dahrén, 2019). Using HPLC is effective for liquid samples. Different additional techniques have been used in the studies for parallel testing or when the analytical technique has lower capabilities for detecting a substance. The advantages and disadvantages can be summarised in Table 5.

The study shows that container gas measurement in the Port of Rotterdam is performed outside a laboratory setting, where both sampling and analysis are performed. This put pressure on the feasibility of implementing capable measuring equipment to perform the measurements. Enabling the chemical measurement in import container ports enables fast identification, detection, and categorisation of the potentially toxic chemicals inside shipping containers. This study shows a variety of measuring equipment that has been used in several studies (Bauer et al., 2010; de Groot, 2007; Frost, 2010; Hinz et al., 2021; Knol-de Vos, 2002; Luyts & Mück, 2011; Mück & Stock, 2012; Svedberg & Johanson, 2017; Tortarolo, 2011; Wagstaffe et al., 2012). Import containers are measured in industrial environments, and each analysis needs to be performed efficiently and in a short period of time because it is a service offered (K. Schwartz, personal communication, March 1, 2023).

4.8 Comparison Between the Studies

The literary appearances of different methods used for detection in different results of detection limit values and, therefore, most likely to be different from daily container gas measurements. All studies found chemicals inside the shipping containers, some of which were toxic. On the other side, without proper documentation, it is difficult for the operator performing the container gas measurement to know if the elevated levels of gaseous chemicals are derived from earlier fumigation of the same container or if it is the goods or packaging materials themselves (K. Schwartz, personal communication, March 1, 2023). All measurements, not limited to any measuring equipment, show that chemical gases can be present in shipping containers.

Table 6. Chemical compounds that have been identified in the relevant literature.

Chemical compounds	Literary Appearances
Alcohols	
2-chloroethanol	(Svedberg & Johanson, 2017)
Ethanol	(Svedberg & Johanson, 2017)
Isobutanol	(Svedberg & Johanson, 2017)
Isopropanol	(Svedberg & Johanson, 2017)
Methanol	(Hinz et al., 2021; Svedberg & Johanson, 2017)
Aldehydes	
Acetaldehyde	(Hinz et al., 2021; Svedberg & Johanson, 2017)
Formaldehyde	(Bauer et al., 2010; Hinz et al., 2021; Knol-de Vos, 2002; Luyts & Mück, 2011; Mück and Stock, 2012; Svedberg & Johanson, 2017; Tortarolo, 2011; Frost, 2010 & Wagstaffe et. al, 2012)
Alkyl halides	
1,2-dibromoethane (Ethylene dibromide)	(de Groot, 2007; Frost, 2010; Hinz et al., 2021 & Wagstaffe et. al, 2012)
Chloroethanol, 2-	(Svedberg & Johanson, 2017)
Chloroform	(Svedberg & Johanson, 2017)
Dichloro-1-fluoro ethane (Freon141b, 1,1-(HCFC-141b))	(Svedberg & Johanson, 2017)
Methyl bromide	(Bauer et al., 2010; de Groot, 2007; Frost, 2010; Hinz et al., 2021; Knol-de Vos, 2002; Luyts & Mück, 2011; Mück & Stock, 2012; Tortarolo, 2011; Wagstaffe et. al, 2012)
Trichloronitromethane (Chloropicrin)	(Bauer et al., 2010; Hinz et al., 2021; Luyts and Mück, 2011; de Groot, 2007; Tortarolo, 2011; Frost, 2010; Wagstaffe et. al, 2012; Mück & Stock, 2012)
Aromatic hydrocarbons	
Benzene	(Bauer et al., 2010; Budnik et al., 2017; de Groot, 2007; Hinz et al., 2021; Knol-de Vos, 2002; Luyts and Mück, 2011; Mück & Stock, 2012; Svedberg & Johanson, 2017; Tortarolo, 2011; Wagstaffe et. al, 2012)
Chlorobenzene	(de Groot, 2007)
Propyl benzene, n-	(Svedberg & Johanson, 2017)
Styrene	(Hinz et al., 2021; Luyts & Mück, 2011; Mück & Stock, 2012; Svedberg & Johanson, 2017; Tortarolo, 2011 & Wagstaffe et. al, 2012)
Toluene	(Hinz et al., 2021; Luyts & Mück, 2011; Svedberg & Johanson, 2017; de Groot, 2007; Tortarolo, 2011; Wagstaffe et. al, 2012; Mück & Stock, 2012)
Xylene	(Mück & Stock, 2012; Svedberg & Johanson, 2017; Tortarolo, 2011)
C2-alkylbenzenes	(Hinz et al., 2021; Wagstaffe et. al, 2012)
M-xylene	(de Groot, 2007; Svedberg & Johanson, 2017)
O-xylene	(de Groot, 2007; Svedberg & Johanson, 2017)
P-xylene	(de Groot, 2007; Svedberg & Johanson, 2017)
Ether	
Dimethoxymethane	(Svedberg & Johanson, 2017)
Dimethyl ether	(Svedberg & Johanson, 2017)
Esters	
Butyl acetate	(Svedberg & Johanson, 2017)
Ethyl acetate	(Svedberg & Johanson, 2017)

Ethyl formate	(Coetzee et al., 2020)
Hexyl acetate, n-	(Svedberg & Johanson, 2017)
Halocarbons	
Tetrafluoroethene, 1,1,1,2-(HFC-134a)	(Svedberg & Johanson, 2017)
Tetrachloromethane	(de Groot, 2007)
Trichloroethylene	(Svedberg & Johanson, 2017)
Dichloro-1-fluoro ethane (Freon141b, 1,1-(HCFC-141b)	(Svedberg & Johanson, 2017)
1,2-Dichloroethane, (Ethylene dichloride)	(Bauer et al., 2010; Budnik et al., 2017; de Groot, 2007; Hinz et al., 2021; Luyts & Mück, 2011; Mück & Stock, 2012; Svedberg & Johanson, 2017; Tortarolo, 2011; Wagstaffe et. al, 2012)
Dichloromethane	(Svedberg & Johanson, 2017)
Hexachlorobutadiene	(de Groot, 2007)
Hydrocarbons	
Cyclohexane	(Svedberg & Johanson, 2017)
Heptane, n-	(Svedberg & Johanson, 2017)
Isobutane	(Svedberg & Johanson, 2017)
Isobutylene	(Svedberg & Johanson, 2017)
Isopentane	(Svedberg & Johanson, 2017)
Methane	(Svedberg & Johanson, 2017)
Octane	(Svedberg & Johanson, 2017)
Pentane, n-	(Svedberg & Johanson, 2017)
Pinene, b-	(Svedberg & Johanson, 2017)
Inorganic gases	
Ammonia	(Hinz et al., 2021; Knol-de Vos, 2002; Luyts & Mück, 2011; Mück & Stock, 2012; Svedberg & Johanson, 2017; Tortarolo, 2011; Wagstaffe et. al, 2012)
Carbon dioxide	(Knol-de Vos, 2002; Luyts & Mück, 2011; Mück & Stock, 2012; Svedberg & Johanson, 2017; Tortarolo, 2011)
Carbon monoxide	(Knol-de Vos, 2002; Luyts & Mück, 2011; Mück & Stock, 2012; Svedberg & Johanson, 2017; Tortarolo, 2011)
Hydrogen cyanide (Hydrocyanic acid)	(Frost, 2010; Hinz et al., 2021; Luyts & Mück, 2011; Mück & Stock, 2012; Tortarolo, 2011; Wagstaffe et. al, 2012)
Hydrogen phosphide (Phosphine)	(Bauer et al., 2010; de Groot, 2007; Frost, 2010; Hinz et al., 2021; Knol-de Vos, 2002; Luyts & Mück, 2011; Mück & Stock, 2012; Svedberg & Johanson, 2017; Tortarolo, 2011; Wagstaffe et. al, 2012)
Oxygen	(Luyts & Mück, 2011; Mück & Stock, 2012; Tortarolo, 2011)
Other	
Ethylene	(Svedberg & Johanson, 2017)
Ethylene oxide	(Svedberg & Johanson, 2017)
Octamethylcyclotetrasiloxane	(Svedberg & Johanson, 2017)
Sulphuryl fluoride (Vikane)	(Bauer et al., 2010; de Groot, 2007; de Groot; Hinz et al., 2021; Knol-de Vos, 2002; Mück & Stock, 2012; Tortarolo, 2011;)
White spirit	(Svedberg & Johanson, 2017)

The total number of chemical compounds described in recent and relevant literature is 56 chemicals, categorised in this study into ten groups, as seen in *Table 6*. Most of the chemicals are hydrocarbons of different forms, i.e., aromatic hydrocarbons, hydrocarbons, and halocarbons. The table above describes chemicals identified in shipping containers in the literature over almost twenty years, from 2002 to 2021. The findings of these chemical compounds have been done with different measuring equipment and sampling methods to identify, detect and categorise these compounds. Some chemicals are more present than others because they have been identified in several studies over a long period of time.

4.9 Chemicals Present in Shipping Containers

The estimated chemicals in shipping containers are higher than in the literature, as seen in *Figure 3*. Based on data obtained from Gasmeststation Nederland B.V., 41 chemicals are labelled as carcinogenic, mutagenic and reprotoxic (CMR). In the literature, only 15 of the airborne chemicals (36,58%) described in the literature review are found to be carcinogenic,

mutagenic and reprotoxic (CMR). Based on these findings, this means that more chemicals in shipping containers can be both carcinogenic, mutagenic and reprotoxic. Different studies have found different concentrations of fumigants reported. Several studies have concluded a correlation between containers and the presence of airborne chemicals present in import shipping containers deriving from the fumigation process (Bauer et al., 2010; de Groot, 2007; Frost, 2010; Hinz et al., 2021; Knol-de Vos, 2002; Luyts & Mück, 2011; Mück & Stock, 2012; Svedberg & Johanson, 2017; Tortarolo, 2011; Wagstaffe et al., 2012).

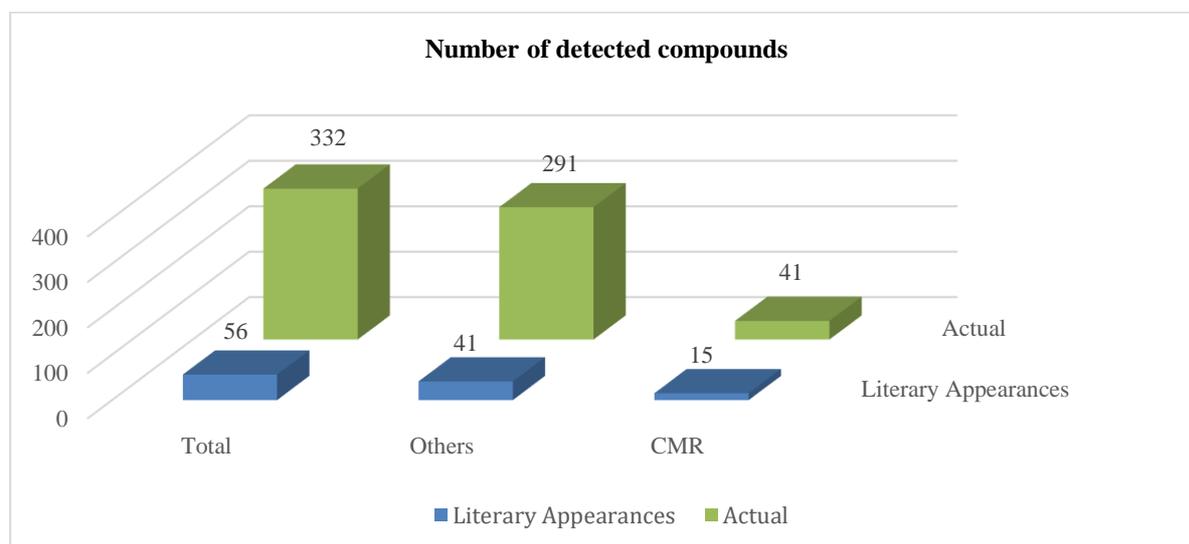


Figure 3. Number of detected compounds in shipping containers. Comparison between chemicals found in the literature study versus the list of chemicals obtained from Gasmeeetstation Nederland B.V. performing gas measurements in the Port of Rotterdam.

The company performing container gas measurements in the Port of Rotterdam claim that they can measure nearly four hundred chemical gases (K. Schwartz, personal communication, March 1, 2023), most unrelated to fumigated containers. They further claim that only five to ten percent of all containers with elevated airborne chemical presence have been fumigated. Currently, they are performing the container gas measurements using an FTIR analyser. The result shows that far more chemicals are present in shipping containers from the cargo and the packaging materials than from fumigation itself (K. Schwartz, personal communication, March 1, 2023).

Figure 3 illustrates the comparison of chemicals in the literature based on field experiments and data from Gasmeeetstation Nederland B.V. on shipping containers. The result indicates that more chemicals can be identified as off-gassing chemicals from the goods or the packaging material and that more chemicals are not toxic and labelled as CMR. The list in the Appendix shows that there is proof that containers may have many types of chemical compounds present in shipping containers. Evidentially, this means that if more containers were analysed, there is a possibility that more chemicals would be detected. Using sensitive measuring equipment would also increase the chances of finding these substances.

4.10 The Buyer of the Measurements

The container gas measurements are a methodology to measure and identify if the container has toxic chemical gases and if there are below the OEL levels. The buyer of this container gas

measurement is the receiver of the goods (K. Schwartz, personal communication, March 1, 2023). This is derived from the Dutch Working Conditions Degree 3.5, where companies are enforced to ensure the safety of their personnel. Container carriers do not have container gas measurements as a procedure for their container handling. In this case, the largest container carrier, MSC, does not perform container measurements as part of its operational activities. Their subsidiaries perform different logistics activities with the containers in the hinterland operation. Fumigation is performed by a third party, meaning the carriers have very little knowledge of the container and its potential safety hazards and can only rely on the documentation provided along the voyage (P. Hägg, personal communication, March 1, 2023).

4.11 The Procedure of Testing, Ventilation, and the Supply Chain

The shipping container is unloaded after a voyage and transported using another transportation method. A truck driver transports the container to its destination. If the receiver has ordered a container gas measurement, the container will be taken to a drive-in facility to be measured before continuing into the supply chain. The container gas measurement is performed today by FTIR-analysis in the Port of Rotterdam (GeoZICHT, 2020). The shipping container is analysed within a few minutes. If rejected due to high concentration levels of chemicals OEL, the container will be transferred to a forced ventilation system and depot. The container then needs to go through a so-called “redo measurement” to ensure the container has concentrations below hazardous exposure limits. If the container has passed the check for the container measurements a certificate is issued stating that the container is safe to enter during a short period after the measurement (K. Schwartz, personal communication, March 1, 2023). The procedure of the container gas measurement and operations can be shown in *Figure 4*.

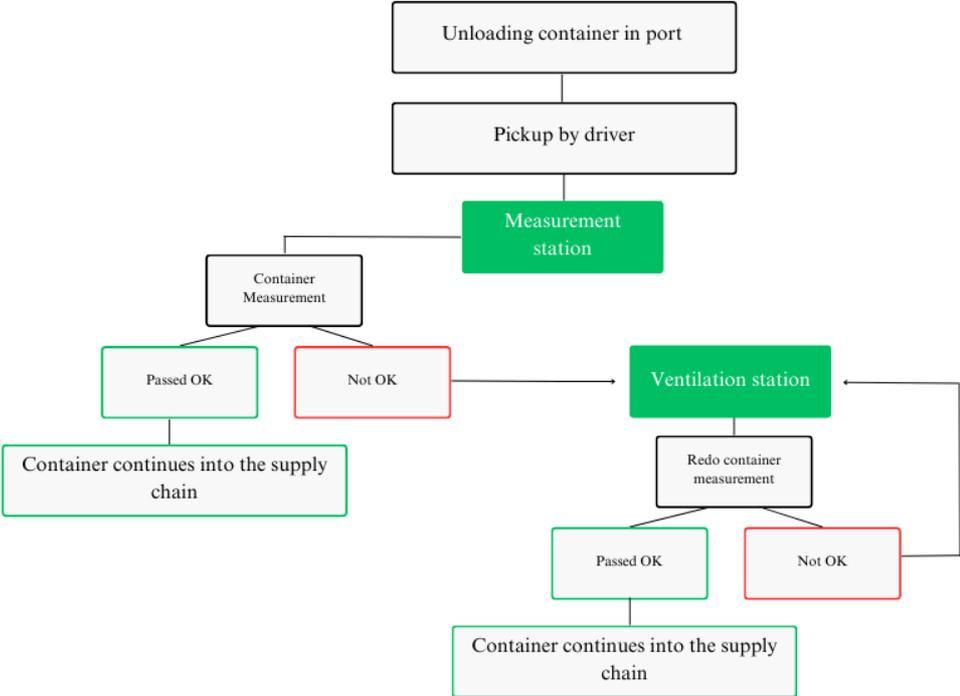


Figure 4. Own schematic illustration of the testing procedure of Gasmeeetstation Nederland B.V. operations.

5. DISCUSSION

Discussion of the results obtained in the Results chapter.

5.1 Potential Bigger Problem Than Discussed

The results clearly show that fumigated containers only represent a minimal number of containers with chemicals present. The shipping container imposes a tremendous potential risk for those working with shipping containers, and preventive actions such as container measurements may reduce the risk of negative occupational exposure. By comparing the literature results against the data obtained from Gasmeststation Nederland B.V., this study shows that many more chemicals are present in shipping containers and are not primarily derived from the fumigation process but from other factors that occur most likely during transportation over long-sea voyages. One way to determine the occurrence of these gases would be to monitor each container during transportation with sensors that monitor humidity or a few known gases. Otherwise, it is not easy to understand when and how these gases occur during transportation.

All previous studies and reports have physically tested several shipping containers. The studies have used different measuring equipment and analytical techniques in different years, most likely during different regional or seasonal periods. The studies show a high total percentage of airborne chemicals being present in shipping containers. The result shows a significant probability that most shipping containers may have elevated levels of toxic airborne chemicals affecting occupational safety upon opening but in different concentration levels. The studies still show a variance in their respective results showing unpredictability and uncertainty about the hazardous risks. The container measurement methodology would allow for excellent personal safety risk assessment and reduces the risk of occupational health accidents.

5.2 Gases are Emitted During Transportation

Several factors enable the presence of chemical substances inside a shipping container. Research has only focused on the findings between fumigants and the presence of these fumigants inside shipping containers. The result of this study shows that other factors, such as air pressure, temperature, and humidity, most likely, are major contributing factors to the occurrence of chemical gases inside the shipping container. It also shows that goods and packaging materials can emit gases. The variance in data is evidence of significant importance in understanding the correlation between packaged goods and chemical substances. An increased number of containers being measured and assessed by a standard and approved measuring methodology would enable an efficient understanding of the correlation between transportation and the occurrence of chemical compounds. Using suitable analytical instrumentation that can perform quantitative and qualitative chemical analysis with small false positive readings within a brief period would allow a greater measuring methodology.

5.3 Experimental Studies with Different Measuring Equipment

It was observed that the studies have been using different types of measuring equipment, some of their detectors and simple measuring equipment such as FTIR and PID. Some studies have combined chromatographic techniques for even more sensitivity in identifying and detecting unknown chemical gases. The fact that different substances are identified in the literature shows

clearly that there is still more to be investigated since there is a variance in the results. The methods may not be reproducible because of the different types of analytical techniques used, and it is not stated, but most likely that different periods of the year of the experiments and different volumes of containers being analysed have resulted in a variance of data. Enabling analytical instrumentation that can analyse both quantitative and qualitative would reduce the false positive readings and ensure reproducibility in the testing. Correction factors can be used to reduce the false/positive readings of a measurement, such as seen in *Appendix*.

Categorising a shipping container with fumigants correlated to specific cargo types can increase awareness of specific cargo having increased risks of fumigants. To conclude if the airborne chemicals are directly a result of 1) the fumigation process, 2) residual trace amounts that are adsorbed by the goods and then emitted or 3) if temperature, air pressure and humidity can not be estimated if not more containers are measured, and the data evaluated.

The results from the research studies are presented in a way that could indirectly argue that correlation and categorisation of chemical substances derive mostly from fumigation and that different types of cargo adsorb it and then emits it. Enabling proper container gas measuring in several ports would increase the data on airborne chemicals in shipping containers, reducing the likelihood of false conclusions.

5.4 Occupational Exposure of Chemical Gases

There may be significantly more containers with elevated levels of chemical gases present in shipping containers than observed in these studies. Container gas measurements may reduce the likeliness of occupational exposure and reduce the risk of occupational accidents working with the loading and unloading of containers. There are several measuring types of equipment, but the amount of chemicals detected tends to be higher when a hyphenated technique has been used, meaning that the analytical method combines a chromatographic technique and a detector. As there is a significant movement of shipping containers worldwide that are transported and handled by different people and organisations, there is a greater probability that many are exposed to occupational health risks. The container gas measurements are an excellent way to increase awareness of the potential risks of shipping containers. The study shows that there is potentially a great problem with chemical gases in shipping containers and that container gas measurement could be proven advantageous. More methods and standardised ways to control the atmosphere inside a shipping container and ensure effective handling in hinterland operations would allow for safety.

There is still a knowledge gap about shipping containers being hazardous with toxic chemical gases inside. The measurements should only be prioritised and used to ensure the safety of personnel, and methods used for the identification and categorisation should only be chosen based on their abilities to detect the concentrations, both quantitative and qualitative. The container gas measurement is part of the supply chain, and therefore speed plays a crucial part in ensuring an effective workflow. Measuring equipment that is evidentially faster than chromatographic techniques, such as the FTIR, may not be able to detect chemicals of interest at lower concentrations due to its lack of a chromatographic component. Fumigation could cause health risks for dockworkers, container unloaders and even end-consumers, there should be more incentives that enforce qualitative chemical analysis of the shipping container in ports. The fact that a gas measurement operator ensures the safety of the container after a measurement should only be reliable if the best method has been used.

5.5 Categorisation of Chemicals in Shipping Containers

The capability to accurately test shipping containers in a preferred time while still being able to analyse and separate a chemical mixture for qualitative analysis is essential (K. Schwartz, personal communication, March 1, 2023).

This study categorises airborne chemicals into groups based on their literary appearances. Most airborne chemicals identified in the literature were some form of hydrocarbon. It was known that FTIR analyses are used in several publications and by Gasmeststation Nederland B.V. This study shows that there is still a variance in the measurements and the reproducibility.

This study identified that studies detected more airborne chemicals in shipping containers that had a combination of analytical instrumentation. An analytical method must be used to identify and quantify specific substances to ensure a precise quantitative and qualitative sample analysis. As most of the studies have found different chemicals that are hydrocarbons, introducing a hyphenated method such as a GC-UV, illustrated in *Figure 5*, would allow for greater quantitative and qualitative analysis since most chemical compounds have their absorption capability in the UV spectrum as seen in *Figure 5*. It would also ensure a better qualitative chemical analysis since a chromatographic analytical technique would be used.

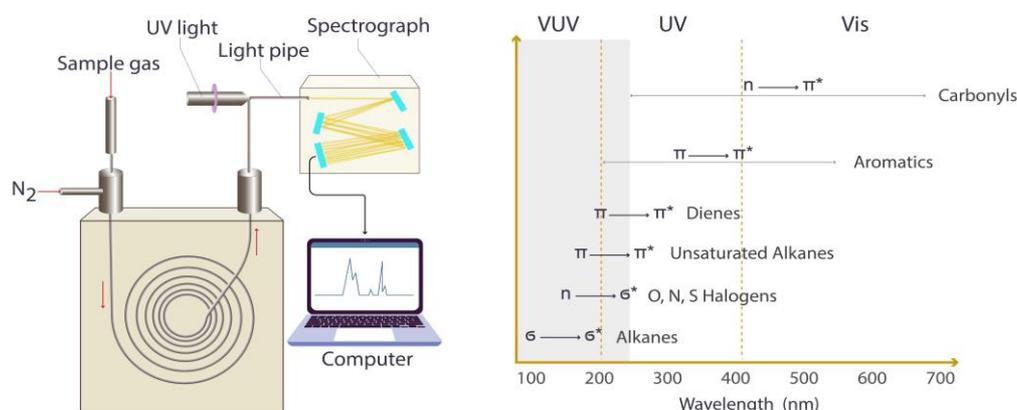


Figure 5. Own schematic illustration of a chromatographic technique, chemical groups and their respective absorption capability in the wavelength region 100 – 700 nm.

5.6 Ensuring a Safe and Correct Testing Procedure

Since the chemical analysis is performed in a time-constrained operation in the supply chain, fast measurements are required to ensure an efficient flow of shipping containers that can be tested. Containers are unloaded during periods when vessels are discharging at the ports. The initial tests need to be fast yet enable reliable and ensure reproducible testing. More containers would be rejected if the container gas measurement could analyse the gas mixture at lower concentrations and have a lower detection limit as it determines the sensitivity. Since the container gas measurement is a service operation that will ensure the occupational safety of

people working with the containers, the containers should be tested with priority to be able to analyse the concentration levels and not the speed of the analytical instruments. The redo of the gas measurements that were initially rejected and have been ventilated should not be time-constrained since the redo measurements could be performed between the busy periods of container arrivals in the port.

5.7 Choosing the Right Analytical Method

Understanding the presence of the chemical substances by identifying and categorising them enables a better probability of choosing the right measuring equipment for the analysis. There is no universal analytical instrument that can measure a broad range of chemical substances in a short time frame. Instruments may differ in their ability of sensitivity, precision, and reproducibility. With the advanced technology being used, the cost, size and price may differ from different technologies and manufacturers, making it problematic for the end customer to choose between analytical systems or detectors. Some instruments may be better for different types of samples and chemical classes. Therefore, understanding the best method for container gas measurement can only be done by understanding the supply chain and the health risks of exposure.

As the chemical analysis is conducted in an industrial environment, ease of use should be considered when performing a container gas measurement. A container gas measurement is a level of chemical analysis; therefore, a lack of knowledge about chemistry and lack of training in the measurement would reduce the likelihood of a proper chemical analysis procedure. At the same time, complex analytical instruments may better identify and detect unknowns in a sample but be more difficult to use. This study has identified and categorised what chemical substances could be present in shipping containers. Container gas measurement with appropriate analytical instrumentation is most likely needed if gases are emitted during transportation. This means that several unknown chemical gases can not be derived from fumigation. Fumigants can be categorised and correlated to the fumigation process, but since there are more chemical gases than just fumigants, container gas measurements are needed.

5.8 Using a Standardised Method with a Combination of Techniques

Increasing the safety and reducing the risk of false positive readings must require combining analytical techniques and instruments. The studies declared that other technologies may have different capabilities for measuring other specific substances. Gasmeeetstation Nederland B.V. is only using a FTIR analyser. Their data shows much more chemical substances than the studies. If they would allow parallel testing with another more profound analytical method in their measurement service, greater security would come, and the false positive readings would decrease. The fact that they issue a certificate declaring the safety with just one measurement technique is not profound. Other analytical techniques, such as chromatographic techniques, can detect more volatiles and semi volatiles chemical compounds than FTIR analysis. The differences in the measurement capabilities in the different studies may depend on the measurement equipment's spectrum libraries and their software. The interpretation of data and the capabilities of identifying and detecting substances may affect the reliability and reproducibility of the measurements.

5.9 Method Discussion

The method used in this study was a combination of a literature review and interviews. Using these specific methods was essential to find relevant and existing research about the topic and appropriate conclusions, with insights from the interviews. This study used a qualitative method to analyse the literature overview and the interviews. The literature could be compared to the data obtained from industry-leading professionals conducting daily operations with shipping containers.

The study did not aim to represent the economic incentives of potential container gas measurements. Still, understanding their daily operations with containers would enable more perspectives and support for the data described in existing research. Using these research methods, the validation of future studies would increase. The research on the consequences of toxic chemicals could also be studied through observations. Still, lack of time and resources have not efficiently enabled the study of the toxicological effects.

Conducting an independent experiment would yield different results due to several factors. These include but are not limited to the number of containers analysed, weather conditions, and the type of equipment used. These variables would influence the outcome and should be considered when interpreting the results of such an experiment.

Prior to the interviews, the respondents were given information regarding their participation in the study and gave their permission before answering any questions. The respondents were also allowed to stop answering questions at any given point during the interview. According to Vetenskapsrådet (2017), several principles should be complied with. With clear instructions, open communication and reliability in the respondents and the information that they gave.

The research methodology can prove the validation and reliability of a study through data collection. Validity means that what is requested is measured in the study using primary resources (Bryman, 2016), which increases the study's validity. Using translated Dutch data could result in discrepancies or inconsistencies in the findings. Translating data may introduce nuances, interpretations or even errors that could affect the accuracy and reliability of the information. Therefore, when relying on translated data, caution should be exercised. The sources and references are good because of the research's reproducibility if done again. To secure these, the methodology was presented clearly to reproduce the study. These steps were visible and clear for the reader, and the study could be produced if followed by the same steps. Reliability is about accuracy and precision in the study (Bryman, 2018). Therefore, if the study were to be performed again, there would be a similar result. Bryman (2018) argues that if reliability and validity are to be high, the study needs to be carefully conducted.

Together, the literature and the interviews gave a deeper understanding of the subject, reducing the risk of indirect false conclusions. Further, the existing research has reproducibility and can be described, identified, and synthesised, according to Fink (2019). This is important for ensuring the validity and reliability of the research findings.

The quality of the substance list and data presented in this study and the *Appendix* may be influenced by the measuring technology and methodology quality. Also, since the data are significantly higher in volume compared to the literary appearance, it may be proof that containers have more substances due to a lot of test data. The operator performs approximately 60,000 gas measurements annually, and this data of substances in the *Appendix* has been

accumulated over several years, evidentially since the beginning of their operations. It is possible that the data from Gasmeetstation Nederland B.V. is accurate and has significant great value, giving insights into the possibilities of what chemical substances may be present in shipping containers. There is an uncertain possibility that earlier research studies had older measuring equipment and that the technology of the measuring equipment has been improved.

Other factors may have affected the results in the research studies as well the substance list in the *Appendix*. The direct comparison of the substances should be approached with caution due to some discrepancies. Firstly, the list provided in the *Appendix* does not reflect a direct measurement of a handful of chosen containers. Additionally, the methods and data collection that has been used in the research studies differs from those employed in the compiling list found in the *Appendix*.

6. CONCLUSION

The study's conclusions are presented in the following chapter. The conclusion is based on the research questions as well as the results. Lastly, recommendations for further research are presented.

The study aimed to identify and categorise what toxic chemical gases might be present in shipping containers and under what circumstances they can potentially occur. This study concluded that there is a variance in the data. Furthermore, the study found that several different airborne chemical gases could be present in shipping containers, and some are toxic. The study also concluded that chemical gases could be emitted during transportation from sources other than the fumigation process itself. Several sampling methods and measuring equipment have been described and compared for measuring shipping containers. It was concluded that implementing container gas measurement as a service could reduce occupational health risks and increase awareness of the potential hazards of the container.

This study enhances the arguments of the probability that gaseous chemicals most likely can be affected by temperature, air pressure and humidity. These factors increase the risk of the potential presence of chemical gases in shipping containers that might be emitted from the packaging materials and goods. The study also shows significantly more chemicals than previously mentioned in research, that can be found in shipping containers, and some may be toxic and hazardous. The study describes different analytical techniques and sampling methods used for container measurements.

6.1 Recommendations for Further Research

During this study, several areas within this topic have been discovered. Some are correlated to the topic and relevant but could not be further investigated in this study. Therefore, it would have been interesting to investigate economic and local incentives for implementing container gas measurement facilities in ports and hinterland operations.

Another interesting study would have been to know why there is a lack of knowledge on this topic and the requirements to enable more container gas measurements. Another interesting study that would be interesting to read would be a study on how personnel can be monitored from acute intoxication of symptoms and if there are methods that could allow diagnosis of acute symptoms.

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APPENDIX 1

Chemical compound	CAS number	Formula	Exposure limit (ppm)	Correction factor P10 (10.6 µV)	Carcinogenic, Mutagenic, or Reproductive (CMR)	Correlation
Carbon dioxide	1344-84-9	CO ₂	5000	NB		Standard present in the air (400 ppm); fumigant used for ripen fruit
Carbon monoxide	630-08-0	CO	20	NB		Reaction product (especially natural reaction)
Nitrous oxide	10024-97-2	N ₂ O	80	NB		Hydroxide
Methane	74-82-8	CH ₄	1000 *	NB		Reaction product (especially natural reaction / combustion reaction) // * no TLV in NL; TLV EU taken as a reference
Nitrogen monoxide	10102-43-9	NO	2	NB		Fumigant agent for foam, cleaning agent
Ammonia	7664-41-7	NH ₃	20	9.7	CMR	Adhesive, formalin, disinfectant
Formaldehyde	50-00-0	CH ₂ O	0.12	NB	CMR	Fumigant; sterilization of medical goods
Ethylene oxide	75-21-8	C ₂ H ₄ O	0.5	13	CMR	Fumigant; sterilization of medical goods
Benzene	71-43-2	C ₆ H ₆	1	0.5	CMR	Gasoline, adhesives, paint
Toluene	108-88-3	C ₇ H ₈	40	0.5	CMR	Gasoline, adhesives, paint
Ethyl benzene	100-41-4	C ₈ H ₁₀	50	0.5	CMR	Gasoline, adhesives, paint
M-xylene (2-alkylbenzene)	108-38-3	C ₈ H ₁₀	48	0.5	CMR	Gasoline, adhesives, paint
O-xylene (2-alkylbenzene)	95-47-6	C ₈ H ₁₀	48	0.56	CMR	Gasoline, adhesives, paint
p-xylene (2-alkylbenzene)	106-42-3	C ₈ H ₁₀	48	0.48	CMR	Gasoline, adhesives, paint
Methyl boronic acid	74-83-0	CB ₂ H ₇ O	0.25	1.7	CMR	Fumigant; natural products (wood)
1,2-dithioethane	107-66-3	C ₂ H ₄ S ₂	1.7	NB	CMR	Polymer articles, plastics, varnishes
Chloroform (trichloromethane)	76-06-2	CCl ₃ H	0.1	NB	CMR	Fumigant; marker for methyl bromide
Styrene	100-42-5	C ₈ H ₈	25	0.4	CMR	Gasoline, adhesives
Hydrogen phosphide (phosphine)	7803-51-2	PH ₃	0.1	3.9	CMR	Fumigant; food products
Sulfury fluoride	2699-79-8	SO ₂ F ₂	2.5	NB		Fumigant; substitute for methyl bromide
Hydrogen cyanide	74-90-8	HCN	0.9	NB		Fumigant; hydrogen cyanide gas
Carbon disulfide	75-15-0	CS ₂	5	1.2	CMR	Solvent, natural product (marshes/volcanic eruptions)
Acetone	67-64-1	C ₃ H ₆ O	510	1.1		Solvent, among others, in paint, glue
Dichloromethane	75-09-2	CH ₂ Cl ₂	100	NB		Blowing agent; soft foam, solvent, paint remover
Ethane	74-84-0	C ₂ H ₆	1000 *	NB		Natural gas // * no TLV in NL; TLV EU taken as a reference
Propane	74-98-6	C ₃ H ₈	1000	NB		Camping gas, blowing agent // * no TLV in NL; TLV EU taken as a reference
Butane	106-97-4	C ₄ H ₁₀	600	6.7		Blowing agent, camping gas
Hexane	110-54-3	C ₆ H ₁₄	20	4.3	CMR	Solvent
Octane	115-55-9	C ₈ H ₁₈	300 *	1.8		Solvent, gasoline // * no TLV in NL; TLV EU taken as a reference
Isopentane	78-78-4	C ₅ H ₁₂	600	8.2		Blowing agent for Styrofoam, solvent
Ethylene (ethene)	74-85-1	C ₂ H ₄	250	9		Refrigerant during fruit ripening process
Propylene (propene)	115-07-1	C ₃ H ₆	500	1.4		Basic substance for the chemical industry
Cyclohexane	110-82-7	C ₆ H ₁₂	200	1.4		Solvent
Alfa pinene	80-56-8	C ₁₀ H ₁₆	25	0.31		Natural product in pine wood, perfume
Beta pinene	127-91-3	C ₁₀ H ₁₆	25	0.37		Natural product in pine wood
Delta-3-carene	13466-78-9	C ₁₀ H ₁₆	25	0.35		Natural product in rosemary, carrots
Limonene	5989-77-5	C ₁₀ H ₁₆	25	0.33		Natural product in lemons
Formic acid	64-18-6	CH ₂ O ₂	3	NB		Formic acid
Acetic acid	64-19-7	C ₂ H ₄ O ₂	10	2.2		Acetic acid
Methyl acetate	79-20-9	C ₃ H ₆ O ₂	30	6.6		Perfumers, rubbers
Ethyl acetate	141-78-6	C ₄ H ₈ O ₂	200	4.6		Perfumers, rubbers
2-butylethyl acetate	112-07-2	C ₆ H ₁₂ O ₂	20	1.3		Solvent in paint, coating ink // * no TLV in NL; TLV EU taken as a reference
Dimethyl methylene	109-87-5	C ₃ H ₈ O ₂	1000	1.51		Solvent, cleaning agent, aroma substance // * no TLV in NL; TLV EU taken as a reference
Acetaldehyde	75-07-4	CH ₃ CHO	20	6	CMR	Perfumers, medicines, vitamins (in flavor)
Methyl ethyl ketone (2-butanone)	78-93-3	C ₄ H ₈ O	200	0.9	CMR	Solvent, among others, in paint, glue
Methanol	67-56-1	CH ₃ O	100	10	CMR	Solvent in rubber, disinfectant, production process / chemical reaction product
Ethanol	64-17-5	C ₂ H ₅ O	135	6	CMR	Solvent in rubber, disinfectant, production process
Isopropanol	67-63-0	C ₃ H ₇ O	250	6	CMR	Solvent in rubber, disinfectant, production process
Ethylene dibromide	106-93-4	C ₂ H ₄ Br ₂	0.00025	NB	CMR	Fumigant, flame retardant, used in waxes
Heptane	142-82-5	C ₇ H ₁₆	290	2.35		Solvent, gasoline
Isobutane	75-28-5	C ₄ H ₁₀	1000	100		Blowing agent polyurethane foam, camping gas
pentane	109-66-0	C ₅ H ₁₂	600	8		Blowing agent for Styrofoam, solvent
iso-octane	504-94-1	C ₈ H ₁₈	300 *	1.2		Solvent, gasoline // * no TLV in NL; TLV EU taken as a reference
butyl acetate	123-86-4	C ₆ H ₁₂ O ₂	30	2.38		Solvent for paints and adhesives, fragrance
propionic acid	79-09-4	C ₃ H ₆ O ₂	10	NB		Preservative
Nesane	111-84-2	C ₈ H ₁₀	100	1.4		Solvent, gasoline
Undecane	1120-21-4	C ₁₁ H ₂₄	NB	NB		Solvent, gasoline
1-methoxy-2-propyl acetate	108-65-6	C ₆ H ₁₂ O ₃	100	NB		Cleaning agent / solvent paint, coating
Isopropyl acetate	108-21-4	C ₅ H ₁₀ O ₂	100	NB		Solvent paint, ink, perfumes // * no TLV in NL; TLV EU taken as a reference
Znethoxyethyl acetate	110-98-6	C ₅ H ₁₀ O ₃	0.16	2.6	CMR	Solvent paint, coating
1,3-butadiene	106-99-0	C ₄ H ₆	1	0.85	CMR	Rubber

63	Decane	124-18-5	C10H22	NB		1,4	Solvent, gasoline
64	Acetic acid anhydride	108-24-7	CH3CO3	0,5		6,1	Solvent, chemistry
65	Ethyl lactate	97-64-3	CH3HCO3	5		3,2	Solvent, natural products (wines, fruit, chicken)
66	menthol	89-78-1	C10H20O	8 **		NB	Flavoring agent (peppermint flavor) // * no TV in NL; TV EU used as a reference
67	methyl formate	107-31-3	CH3HCO2	50		NB	Paint, insecticide, synthesis of drugs
68	isobutane	107-83-5	GH4	200		NB	Solvent, cleaning agent
69	propionaldehyde	123-98-6	CH3CO	20		1,9	Synthesis of plastics, pesticides, drugs, and fragrances // * no TV in NL; TV EU taken as a reference
70	acrolein	107-02-8	CH3HO	0,02		3,9	Biocide, intermediate for other substances (acryic acid, methionine)
71	ethyl-3-ethoxypropionate	793-69-9	CH3HCO3	100		0,75	Paints, coatings // * no TV in NL; TV EU taken as a reference
72	2-ethoxyethyl acetate	111-15-9	GH12O3	2			Solvent
73	acetylene	74-86-2	CH2	1000 *		NB	Autogenous welding, precursor preparation of plastic // * no TV in NL; TV EU taken as a reference
74	diethyl ketone	96-22-0	CH3HCO	200 *		NB	Synthesis of medicines, pesticides and fragrances and flavors // * no TV in NL; TV EU taken as a reference
75	Cyclohexanone	108-94-1	GH10O	10		0,82	Solvent, paint industry
76	2-ethylhexylaldehyde	123-05-7	GH16O	0,25 *		NB	Synthesis agent in the chemical sector // * no TV in NL; TV REACH used as a guideline
77	methyl acrylate	96-33-3	CH3HCO2	5		3,7	Synthesis agent in the chemical sector
78	methyl methacrylate	80-62-6	CH3HCO2	50		1,5	Plastics, adhesives
79	1-propanol	71-23-8	CH3HO	100 *		5	Solvent in organic chemistry, cleaning agent // * no TV in NL; TV EU used as a reference
80	1-butanol	71-36-3	GH4HCO	20 *		4,7	Solvent in organic chemistry, cleaning agent // * no TV in NL; TV EU used as a reference
81	2-butanol	78-92-2	GH4HCO	100 *		3	Solvent in organic chemistry, cleaning agent // * no TV in NL; TV EU used as a reference
82	Z-methoxy ethanol	109-86-4	CH3HCO2	0,18		2,4	Solvent for dyes, resins, varnish
83	methyl isobutyl ketone	108-10-1	GH12O	25		0,8	Solvent, extraction agent
84	furfuryl alcohol	98-00-0	GH12O	5 *		0,8	Flavoring agent, in the production of resins, adhesives, paints, coatings // * no TV in NL; TV EU used as a reference
85	diethyl ether	60-29-7	GH10O	100		1,1	Solvent, anesthetic // * no TV in NL; TV EU used as a reference
86	methyl tert-butyl ether	1634-04-4	GH12O	50		0,9	Solvent, octane rating improver in gasoline
87	propanitrile	107-12-0	CH3HN	NB		NB	Solvent, precursor
88	isobutanol	78-83-1	GH10O	50 *		3,8	Solvent // * no TV in NL; TV EU used as a reference
89	methyl amine	74-89-5	CH3N	5 *		1,2	Synthesis of various chemicals // * no TV in NL; TV EU used as a reference
90	dimethylamine	124-40-3	CH3N	1		1,5	Synthesis of various chemicals
91	trimethylamine	75-50-3	CH3N	0,4		0,9	Synthesis of various chemicals
92	tetrakisethylamine	122-38-4	CH3N	20		0,54	Dry-cleaning
93	triethylamine	122-44-8	GH13N	1 *		0,9	Synthesis of various chemicals // * no TV in NL; TV EU used as a reference
94	1,1,1-trichloroethane	79-01-6	CH3Cl3	100		0,54	Degreaser, solvent
95	1,1,1-trichloroethane	71-55-6	CH3Cl3	100		0,82	Solvent
96	Vinylidene chloride	75-35-4	CH2Cl2	2			Solvent
97	freon 22	75-45-6	CHClF2	1000		NB	Refrigerant
98	chloroform	67-66-3	CHCl3	1		NB	CMR
99	freon 32	75-10-5	CH2F2	NB		NB	Solvent, anesthetic, used to glue pieglass
100	freon 134a	811-97-2	CH2F2	1000		NB	Refrigerant
101	Freon 143a	420-46-2	CH3F3	5000 *		NB	Refrigerant // * no TV in NL; OEL of EU used as a reference
102	Freon 124	2832-88-0	CH2ClF4	NB		NB	Refrigerant
103	Freon 23	75-46-7	CH3F	NB		NB	Refrigerant
104	silicon tetrafluoride	7783-61-1	SiF4	NB		NB	Refrigerant
105	1,1-dichloroethane	71-41-0	GH12O	20 **		NB	Organic synthesis, microelectronics
106	methyl chloride	75-34-3	CH3Cl	100		NB	Fragrance industry // ** no OEL in NL; OEL of REACH is used as a reference
107	freon 125	74-87-3	CH3F	25		NB	Flame retardant, insecticide, solvent for plastics, oils, and fats
108	freon 11	354-33-6	CH3F5	500 *		NB	Solvent, refrigerant
109	freon 12	75-69-4	CF3F	1000		NB	Refrigerant // * no OEL in NL; OEL of EU used as a reference
110	freon 11	75-71-8	CF2Cl2	1000		NB	Refrigerant
111	freon 13B1	75-63-8	CF3Br	1000 *		NB	Refrigerant // * no OEL in NL; OEL of EU used as a reference
112	Freon 14	75-73-0	CF4	NB		NB	Refrigerant
113	sulfur hexafluoride	2551-62-4	SF6	1000		NB	Used in the electrical industry
114	freon 114	76-14-2	C2DF4	1000		NB	Refrigerant
115	freon 115	76-15-3	C2DF5	1000		NB	Refrigerant
116	freon 116	76-16-4	CF3F6	NB		NB	Refrigerant
117	freon 123	306-83-2	CF3CF2F3	10 *		NB	Refrigerant // * no OEL in NL; OEL of EU used as a reference
118	freon 113	76-13-1	C2CF3F3	150		NB	Refrigerant // * no OEL in NL; OEL of EU used as a reference
119	freon 128	75-68-3	C2HClF2	2000		NB	Refrigerant
120	freon 218	76-19-7	C3H8	NB		NB	Refrigerant
121	1,2,3-trimethylbenzene	526-73-8	GH12	20		NB	Solvent for gasoline, adhesives
122	1,2,4-trimethylbenzene	95-63-6	GH12	20		NB	Solvent for gasoline, adhesives
123	freon 133A	75-88-7	CH2ClF3	NB		NB	Refrigerant
124	2,3-butadione	431-03-8	GH6O2	0,02		NB	Natural byproduct of fermentation, solvent
125	2-acetylfluorene	1192-62-7	GH6O2	NB		NB	Synthesis of various chemicals and drugs
126	2-ethylfluorene	611-14-3	GH12	NB		NB	Solvent
127	3-ethylfluorene	620-14-4	GH12	NB		NB	Solvent

128	1,3,5-trimethylbenzene	108-67-8	CH12	20	NB			Solvent for gasoline, adhesives
129	phenol	108-95-2	C6H6O	2	NB			Raw material for plastics and dyes
130	acrylic acid	79-10-7	CH3CO2	10	NB	12		Production of plastics; resins, paints; ink, glue // * no OEL in NL; OEL of EU is used as reference
131	uran	110-00-9	CH4O	NB	NB		CMR	Solvent, resins
132	chloroacetyl chloride	79-04-9	CH2ClCO	0.05	NB			Intermediate in the production of various drugs
133	4-ethyltoluene	622-96-8	C9H12	NB	NB			Solvent, production of polystyrene
134	isoflurane	28572-96-7	C3H2ClF5O	20	NB			anesthetic
135	sevoflurane	28572-96-6	C4H7FO	10	NB		CMR	Anesthetic gas // * no OEL in NL; OEL of EU directive is used as reference
136	halothane	151-67-7	CHBrClF3	0.05	NB			local anesthetic, solvent for oils and fats
137	ethylchloride	75-00-3	C2H5Cl	100	NB			local anesthetic, solvent for oils and fats
138	deflurane	57041-67-5	CH2F6O	10*	NB			Anesthetic // * no OEL in NL; OEL of EU is used as reference
139	cyclopentane	142-29-0	C5H10	NB	NB			Synthetic of plastics
140	ethylmercaptan	75-08-1	C2H6S	0.5*	NB	0.56		Fragrance to odorless hazardous substances // * no OEL in NL; OEL of EU is used as reference
141	oxygen difluoride	7783-41-7	OF2	0.05*	NB			no OEL in NL; OEL of EU is used as reference
142	dimethyl sulfide	75-18-3	C2H6S	600*	NB	0.44		Blowing agent, solvent in organic chemistry // * no OEL in NL; OEL of EU is used as reference
143	cyclopropane	287-92-3	C3H6	0.01	NB			Solvent used in rubber production
144	diborane	19827-45-7	B2H6	1	NB			Reagent in organic synthesis (e.g. of drugs)
145	diacyan	460-19-5	C2N2	1	NB			Production of elemental boron
146	boron trichloride	10294-34-5	BCl3	NB	NB			acts as a catalyst in chemical reactions
147	boron trifluoride	7537-07-2	BF3	0.07	NB			Fluorating agent in food product // * no TV in NL; TV EU used as reference
148	Dimethyl disulfide	624-92-0	C2H6S2	0.5*	0.2			Flavoring agent in food product // * no TV in NL; TV EU used as reference
149	carbonyl sulfide	463-58-1	CS	5*	NB			Catalyst, smells like rotten eggs // * no TV in NL; indicative TV from Chemical handbook
150	glutaraldehyde	111-30-8	C5H8O2	0.02	0.8			Disinfectant, active ingredient in some biocides
151	hydrogen bromide	10035-10-6	HBr	2*	NB			Synthetic agent // * no TV in NL; TV EU used as reference
152	hydrogen chloride	7647-01-0	HCl	5*	NB			Hydrochloric acid (aqueous variant) // * no TV in NL; TV EU used as reference
153	boron trifluoride	75-25-2	BF3	0.5*	2.5			Synthesis of medicines // * no TV in NL; TV EU used as reference
154	1-butene	106-98-9	C4H8	250*	0.9			Solvent for rubber // * no TV in NL; TV EU used as reference
155	phlegme	75-44-5	CO2	0.02*	NB			Production of dyes, pesticides, and medicines // * no TV in NL; TV EU used as reference
156	silane	7803-62-5	SiH4	0.5*	NB			used in the etching of DNA carriers // * no TV in NL; TV EU used as reference
157	tetramethyl orthosilicate	681-54-5	Si(CH3)4O4	0.3	1.9			Organic synthesis
158	hydrogen fluoride	7664-39-3	HF	2*	NB			Solvent in laboratories, etchant in glass industry // * no TV in NL; TV EU used as reference
159	Vinyl acetate	108-05-4	CH3CO2	5	1.2			Intermediate of polymers
160	Vinyl chloride	75-01-4	CH2Cl	3	2			Monomer of PVC (polyvinyl chloride)
161	2-ethoxyethanol	110-80-5	CH3OCH2	2	1.3		CMR	Solvent in commercial and industrial applications
162	acrylonitrile	107-13-1	CH3CN	1*	NB		CMR	Manufacture of plastics // * no TV in NL; TV EU used as reference
163	trimethylsilylamine	24872-90-3	CH3O3Si	NB	NB			Intermediate in chemistry
164	furfural	98-01-1	C5H4O2	2	0.92			Raw material for medicines
165	methacrylic acid	79-41-4	CH3CO2	20	NB			Production of polymers // * no TV in NL; TV EU used as reference
166	methyl cyclohexane	108-87-2	C7H14	50*	0.97			Solvent
167	methyl cyclopentane	96-37-2	C6H12	50*	NB			Solvent // * no TV in NL; TV EU used as reference
168	sulfur dioxide	7446-09-5	SO2	0.25	NB			Production of sulfuric acid // * no TV in NL; TV EU used as reference
169	butyric acid	107-92-6	CH3CO2	10**	NB			Synthesis agent // ** no TV in NL; TV REACH used as reference
170	1-propoxy-2-propanol	1569-01-3	CH3OCH2	45**	NB			ink, toner, paint, coating // ** no TV in NL; TV REACH used as reference
171	1,3-dioxolane	646-06-0	CH3O2	20*	2.3			Paint, coating, plastic, rubber // * no TV in NL; TV REACH used as reference
172	2-amino-1-butanol	96-20-8	CH3NH2	0.4**	NB			Solvent // * no TV in NL; TV REACH used as reference
173	nitrogen dioxide	10102-44-0	NO2	0.3	1.6			Explosives
174	aniline	62-53-3	C6H5N2	0.25	0.48			Raw material for chemistry
175	anilol	100-66-3	C7H8O	NB	0.8			Perfume, solvent
176	1-butoxy-2-propanol	5131-66-8	C7H16O2	50**	NB			Solvent, paint, coating // ** no TV in NL; TV based on REACH as reference
177	butylglycol	112-34-5	C8H18O2	10**	NB			Solvent for oil, dyes, stains, polymers // ** no TV in NL; TV based on EU as reference
178	ammonioxyethanol	929-06-6	CH3NH2O	0.1**	NB			Solvent, paint, coating, electronic products // ** no TV in NL; TV based on REACH as reference
179	chlorobenzene	108-90-7	C6H5Cl	5*	0.4			Solvent, raw material for dyes and rubber // * no TV in NL; TV based on EU as reference
180	chloromethyl chloroformate	22128-52-7	C2H2Cl2O2	NB	NB			Production of other chemicals
181	crs-1,2-dichloroethane	540-59-0	CH2Cl2	200	0.8			Solvent for resins, varnishes, waxes, and polymers
182	diethylamine	70-99-7	CH3NH	5	1			Intermediate in chemistry, additive for paints and coatings
183	dichloromethane	75-43-4	CH2Cl2	10	NB			Refrigerant
184	Freon113a	34-38-5	C2Cl3F3	NB	NB			Refrigerant // * no TV in NL; TV based on EU as reference
185	Freon13B1	75-63-8	CF3Br	1000*	NB			Flavor and fragrance
186	methyl salicylate	119-36-8	C8H8O3	NB	0.2			Raw material for chemistry, fumigant
187	naphthalene	91-20-3	C10H8	10	0.42			Comments, solvent for color and flavorings, e-cigarettes
188	1,2-propanediol	57-55-6	C3H8O2	NB	5.5			Solvent for fragrances, produced by fermentation
189	isopentyl alcohol	123-51-3	C5H12O	25	NB			Solvent, plastics
190	metacrylonitrile	136-98-7	C4H5N	1	NB			Solvent in chemistry, explosives
191	nitrobenzene	98-95-3	C6H5NO2	0.2	1.9		CMR	Flavor and fragrance
192	carvone	6485-40-1	C10H14O	NB	NB			

193	o-cresol	108-39-4	C7H8O	5 *	1	Solvent, raw material for pharmaceuticals and pesticides // * No TV in NL, based on guidelines of the chemistry card book
194	p-cresol	106-44-5	C7H8O	5 *	1.4	Solvent, raw material for pharmaceuticals and pesticides // * No TV in NL, based on guidelines of the chemistry card book
195	m-cresol	95-48-7	C7H8O	5 *	0.5	Solvent, raw material for pharmaceuticals and pesticides // * No TV in NL, based on guidelines of the chemistry card book
196	ozone	10028-15-6	O3	0.06	NB	Dishwashing, ozone layer
197	methone	89-80-5	C10H8O	NB	NB	Pesticide
198	tetrahydrofuran	109-99-9	C4H8O	50 *	1.2	Solvent for PVC, polystyrene, glue, and varnish // * no TV in NL, TV based on EU as reference
199	arzne	7182-43-1	A49	0.05 *	1.9	Semiconductor, medical treatment // * no TV in NL, TV based on EU as reference
200	pyridine	110-86-1	C5H5N	0.23	0.2	Solvent, pesticide // * no TV in NL, TV based on EU as reference
201	methyl methacryl	74-99-1	C5H8	0.5 *	0.54	Solvent
202	Cis-2-pentene	67-20-3	C5H10	NB	NB	Solvent
203	Trans-2-pentene	646-04-8	C5H10	NB	NB	Solvent
204	Dimethyl carbonate	616-38-6	C6H8O3	5 **	60	Solvent for rubber, varnish // ** No TV, based on REACH guidelines
205	Hexene	592-41-6	C6H12	50 *	0.8	Grafting, polymerization reactions // * no TV in NL, TV based on EU as reference
206	Ethylcyclohexane	1678-91-7	C8H16	NB	NB	Solvent
207	Isosafrole	120-58-1	C10H10O2	NB	NB	Solvent
208	Hexanoic acid	142-62-1	C6H12O2	5 *	2.4	Formation of polymers // * no TV in NL, TV based on EU as reference
209	Hexanoic acid	123-72-8	C6H8O	20 *	1.8	Food packaging, lubricant
210	Butyraldehyde	599-20-4	C6H8O2	NB	NB	Solvent // * no TV in NL, TV based on EU as reference
211	o-Tolaldehyde	599-86-3	C7H8O2	10 *	NB	Solvent, flavor and fragrance
212	Isobutyraldehyde	66-25-1	C6H12O	10 *	NB	Synthesis of aroma and pharmaceutical // * no TV in NL, TV based on EU as reference
213	Hexanal	4170-30-3	C6H12O	0.1 *	1.1	Flavor and fragrance // * no TV in NL, TV based on EU as reference
214	Coronadialdehyde	100-52-7	C7H8O	1 *	NB	Present in food, cigarettes smoke // * no TV in NL, TV based on EU as reference
215	Benzaldehyde	674-82-8	C7H6O	NB	2	Present in food (almonds), chemical industry // * no TV in NL, TV based on EU as reference
216	Diketene	103-79-7	C8H10O	NB	NB	Organic chemistry (pharmaceutical, paint, insecticide)
217	Benzyl methyl ketone	75-65-0	C10H10O	100	2.9	Production of MDMA
218	t-Butanol	625-86-5	C6H8O	NB	NB	Solvent, cleaning agent
219	2,5-dimethylfuran	108-98-5	C6H8O	0.5 *	NB	Biofuel
220	Benzene(Thiophene)	75-31-0	C6H6S	5 *	1.1	Synthesis of dyes, crop protection agents // * no TV in NL, TV based on EU as reference
221	Isopropylamine	75-05-8	C3H9N	20 *	NB	Production of plastics, rubber, pharmaceuticals // * no TV in NL, TV based on EU as reference
222	Acetanilide	68-12-2	C8H9NO	5	0.2	Pesticides, production of resins, perfumes, rubber // * no TV in NL, TV based on EU as reference
223	Dimethylformamide	109-75-1	C4H9N	NB	NB	Solvent
224	Allylamine	111-26-2	C3H7N	NB	NB	Solvent
225	Hexylamine	143-16-8	C8H17N	NB	NB	Solvent
226	Dibutylamine	100-74-3	C6H13NO	5 *	1.2	Solvent
227	Cyclohexylamine	503-38-8	C8H15NO	NB	NB	Solvent for synthesis of plasticizers, rubber, insecticides // * no TV in NL, TV based on EU as reference
228	Ethylmorpholine	592-34-7	C5H9NO2	0.2	NB	Plastic, rubber // * no TV in NL, TV based on EU as reference
229	Dibutylene	541-41-3	C8H16	1	NB	Insecticide
230	Bulky chloroformate	109-61-5	C2H3ClO2	0.2	NB	Solvent in the pharmaceutical industry
231	Ethyl chloroformate	79-22-1	C3H5ClO2	0.2	NB	Solvent in the pharmaceutical industry
232	Propyl chloroformate	79-44-7	C4H7ClO2	0.005 *	NB	Solvent in the pharmaceutical industry // * no TV in NL, TV based on EU as reference
233	Methyl chloroformate	625-36-5	C2H3ClO2	NB	NB	Organic synthesis
234	Dimethylcarbonoyl chloride	462-06-6	C2H4Cl2O	NB	NB	Solvent
235	3-Chloropropionyl chloride	75-31-6	C3H5Cl2O	1000 **	NB	Refrigerant // ** no TV in NL, TV REACH taken as reference
236	Fluorobenzene	1445-75-6	C6H5F	NB	NB	Solvent
237	Freon R132a	4109-96-0	C2H2F2	NB	NB	Organic synthesis
238	Dihopropyl methanephosphonate	10026-64-7	C7H17O3P	NB	NB	Solvent in microelectronics, semiconductor
239	Tetramethyl silane	75-76-3	C4H12Si	NB	NB	Solvent in microelectronics, semiconductor
240	Dichlorosilane	10025-78-2	SiCl2	NB	NB	Solvent in microelectronics, semiconductor
241	Silicon tetrachloride	75-54-7	SiCl4	NB	NB	Solvent in microelectronics, semiconductor, optical fibers
242	Trichlorosilane	124-70-9	CH3Cl2Si	NB	NB	Solvent in microelectronics, semiconductor
243	Methyl dichlorosilane	4525-48-4	CH3ClSi2	NB	NB	Solvent in microelectronics, semiconductor
244	Methyl vinyl dichlorosilane	11719-58-0	C2H4ClSi2	NB	NB	Solvent in microelectronics, semiconductor
245	Ethylmethylchlorosilane	75-78-6	C2H5ClSi2	NB	NB	Solvent in microelectronics, semiconductor
246	Dimethylchlorosilane	75-78-5	CH3ClSi3	NB	NB	Solvent in microelectronics, semiconductor, optical fibers
247	Methyl trichlorosilane	75-77-4	CH3ClSi3	NB	NB	Solvent in microelectronics, semiconductor, optical fibers
248	Dimethylchlorosilane	141-57-1	C2H5ClSi3	NB	NB	Solvent in microelectronics, semiconductor, laboratory glassware
249	Trimethylchlorosilane	98-13-5	CH3ClSi3	NB	NB	Solvent in microelectronics, semiconductor, laboratory glassware
250	Propyltrichlorosilane	149-74-6	C3H7ClSi3	NB	NB	Solvent in microelectronics, semiconductor, laboratory glassware
251	Phenyltrichlorosilane	75-94-5	C6H5ClSi3	0.5 *	NB	Solvent in microelectronics, semiconductor, laboratory glassware
252	Phenylmethylchlorosilane	106-89-8	CH2ClSi3	0.5	8.5	Solvent for polymers, resin, cellulose, paint
253	Vinylchlorosilane	54-11-5	C2H3ClSi3	0.07	2	Organic synthesis
254	Epi-chlorohydrin	872-50-4	C2H4ClO	10 *	0.8	Cigarette smoke
255	(-)-Nicotine	1112-39-6	C10H12N2	NB	NB	Solvent // * no TV in NL, TV based on EU as reference
256	1-Methyl-2-pyrrolidone (NMP)					
257	Dimethylmethoxyamine					Solvent

258	Dimethylhexylsiloxane	78-62-6	GH1602S1	NB	NB		Solvent, cleaning agent, extraction fluid
259	Nitromethane	75-52-5	CHN02	20	NB		Solvent in the perfume industry // * no TLV in NL; TLV EU taken as reference
260	1-Hexanol	111-72-3	GH140	50 *	2.5		Polymer in paints, varnishes, adhesives
261	Butylacrylate	141-32-2	CH1202	2	1.6		Intermediate in the production of plastics, dyes, polymers
262	Propyl amine	107-10-8	CH111	NB	1.1		Solvent
263	Tertiary Butyl Dimethyl Silyl Alcohol	18173-64-3	GH1605	NB	NB		Batteries // * no TLV in NL; TLV EU taken as reference
264	Thionyl chloride	(7719-09-7)	SOCl2	0.1 *	NB		Polymer, plastic, resins
265	Maleic anhydride	108-31-6	CH1303	0.1	NB		Organic synthesis
266	Phosphoric tribromide	7789-68-8	PBr3	NB	NB		Organic synthesis
267	Vinyl bromide	593-60-2	CH198	0.0025	0.2		Applied in medicine, synthesis of vanillin
268	2-Methoxyphenol (Guaiacol)	90-05-1	CH1802	NB	NB	0.86	Solvent
269	1,2-Dimethoxyethane	110-71-4	CH1002	NB	NB		Organic synthesis
270	1,2-Ethanedithiol	540-63-6	CH1652	NB	NB		Organic synthesis
271	1-Hexene	592-76-7	CH14	NB	NB		Organic synthesis
272	1-Pentene	109-67-1	CH10	NB	NB		Organic synthesis
273	Dodecane	112-40-3	CH1426	NB	NB		Solvent
274	Butylamine	109-73-9	GH111	5 *	1.1		Production of chemicals (dyes, rubber, pharmaceutical substances) // * no TLV in NL; TLV EU taken as reference
275	Ethanolamine	141-43-5	CH170	1 *	1.6		Production of chemicals (dyes, rubber, pharmaceutical substances) // * no TLV in NL; TLV EU taken as reference
276	Hexamethyldisiloxane	107-66-0	GH1805E2	NB	NB		Silicone rubber, cosmetics, cleaning agent
277	Isopentyl acetate	123-92-2	CH1402	50	NB		Fragrance and flavor, solvent for paints and varnish
278	Trimethylsilyl	1066-48-6	CH1003	NB	NB		Solvent
279	Propyl acetate	109-60-4	CH1002	100	NB	3.5	Solvent in paints, varnish
280	Tetraethyl orthosilicate	78-10-4	SiCl4O4	5	NB		Binder, protective coating
281	Morpholine	110-91-8	CH190	10 *	NB		Intermediate in the production of pharmaceuticals // * no TLV in NL; TLV EU taken as reference
282	Benzyl chloride	100-44-7	CH171	1 *	0.6		Pharmaceuticals, perfumes, pharmaceutical substances // * no TLV in NL; TLV EU taken as reference
283	Isobutene (2-methylpropene)	115-11-7	CH18	NB	1		Solvent
284	1,2-dichloropropane (propylene dichloride)	78-87-5	CH162	75	NB		Solvent for resins, varnishes, waxes, and polymers
285	Trans-1,2-dichloroethene	156-60-5	CH162	200	0.45		Solvent for resins, varnishes, waxes, and polymers
286	Acetophenone	98-86-2	CH180	10	NB		Solvent, resins
287	Tetrahydrofuran	110-01-0	CH185	50 *	NB		Natural gas additive, solvent, insecticide // * no TLV in NL; TLV EU taken as reference
288	3-Butenitrile	109-75-1	CH151	NB	NB		Solvent
289	4-Fluorobenzene	350-46-9	GH1802	NB	NB		Solvent
290	CS2-butene	590-18-4	CH18	NB	0.9		Solvent for rubber
291	Trans-2-butene	624-64-6	CH18	NB	0.9		Solvent for rubber
292	Perfluoro-1,3-dimethylcyclohexane	335-27-3	CF16	NB	NB		Solvent
293	Ethylene glycol monobutyl ether	111-76-2	GH1402	20	1.2		Solvent, cleaning agent
294	nonanal	124-19-6	CH180	NB	NB		Natural oils, perfume
295	Dimethylsiloxane	121-69-7	GH111	1	NB		Dyes
296	2-(2-hydroxyethoxy)ethyl acetate	124-17-4	CH12004	15	NB		Solvent, paint, coating
297	1,1,2,2-tetrachloroethane	79-34-5	CH162	1	NB		Solvent, refrigerant
298	Acetonil (3-hydroxybutanone)	513-86-0	CH1802	NB	NB		Flavoring, perfume
299	5-Hydroxymethyl-2-furfural	67-47-0	GH1602	NB	NB		Flavoring and fragrance
300	5-Methyl-2-furfural	620-02-0	GH1602	NB	NB		Flavoring and fragrance
301	1-Ethylamine / Ethylamine	75-04-7	CH171	5	0.8		Organic chemistry
302	Propylene oxide	75-56-9	CH160	2.5	6.6		Solvent, sterilizing agent
303	Ethyl formate	109-94-4	CH1602	100	NB		Solvent for cosmetics, pharmaceuticals, cellulose // * no NL; TLV EU taken as reference
304	2,2-Dimethoxypropane	77-76-9	CH1202	NB	NB		Solvent
305	Methyl ether (Dimethyl ether)	115-10-6	CH160	500	3.1		propellant in aerosols
306	Hexamethylsilazane	999-97-3	CH19052	NB	0.2		Solvent in paint products
307	Trimethylborate	121-43-7	CH1903	NB	5.1		Organic chemistry
308	triethyl borate	150-49-6	CH1503	NB	2.2		Organic chemistry
309	Phosphoric oxychloride	10025-87-3	POCl3	0.1	NB		Raw material in the chemical industry
310	1,2-dimethylhydrazine	540-73-8	CH1802	0.01 *	NB		Inducing tumors in animals // * no NL; TLV EU taken as reference
311	Formol 141b	1177-00-6	CH162E	500	NB		Refrigerant
312	decaethylcyclopentasiloxane	541-02-6	CH1905S5	NB	NB		Used in cosmetics, hairdryer
313	Perfluoro-1,2-dimethylcyclohexane	308-98-9	CF16	NB	NB		Solvent
314	Thiopropylene	483-71-8	CS12	NB	NB		Solvent
315	Methyl isocyanate	594-42-3	CH15	0.001	NB		Solvent for paints
316	Trichloroethanesulfenyl chloride	624-83-9	CH130	4.6			pesticides, plastics
317	1-methylimidazol	616-47-7	CH16M2	NB	NB		Solvent
318	Valeric acid (pentanoic acid)	109-52-4	CH1002	NB	NB		Flavoring and fragrance
319	Heptanoic acid	111-14-8	CH1402	NB	NB		Flavoring and fragrance
320	2,3-pentanedione	600-14-6	CH1802	NB	NB		Solvent, flavoring
321	2,3-hexanedione	3848-24-6	GH1002	NB	NB		Solvent, flavoring
322	2,3-heptanedione	96-04-8	CH1202	NB	NB		Solvent, flavoring

323	Isobutyraldehyde	78-84-2	C4H8O	NB	NB	Organic chemistry
324	Butyryl acetate	623-17-6	C7H8O3	NB	NB	Flavouring and fragrance
325	2-methylpyrazine	109-08-0	C5H6N2	NB	NB	Flavouring and fragrance
326	2-methylbutyraldehyde	96-17-3	C5H10O	NB	NB	Intermediate for other substances, flavouring
327	Z-methylfuran	534-72-5	C3H6O	NB	NB	Intermediate for other substances, flavouring
328	Methyl diethanolamine	105-59-9	C5H13NO2	NB	NB	Synthesis of other substances, cleaning and disinfecting agent
329	m-Diethylbenzene	141-93-5	C10H14	NB	0,5	Intermediate for other substances
330	o-Diethylbenzene	135-01-3	C10H14	NB	0,5	Intermediate for other substances
331	p-Diethylbenzene	105-05-5	C10H14	NB	0,5	Intermediate for other substances
332	5-Methyl-2-heptanone	110-12-3	C7H14O	NB	NB	Solvent for paint, varnish
333	[1E,1,3,3-tetrafluoro-1-propene	1645-83-6	C3H2F4	NB	NB	Blowing agent, propellant, refrigerant
-	Explosion level	-	LEL	-	%LEL	
-	Valid for organic compounds	1333-740	VOC	-	ppm	Explosion level is the result of high concentrations of flammable gases
-	Hydrogen	7782-44-7	H2	NB	100	PID/VOC is the result of gases with an ionization potential four sensors <10.6 eV)
-	Oxygen		O2	NB	19-23	Standard 20.9 vol%, low oxygen is due to the presence of high concentrations of other gases.

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