

Safety procedures in the transport of flammable and oxidizing materials - a case study of thiophene and zinc bromate

Slavka Durlević^a

^a The Academy of Applied Studies: Leposavic, Serbia

ARTICLE INFO

DOI: 10.31075/PIS.72.01.05
Professional paper
Received: 05.02.2026.
Accepted: 04.03.2026.
Corresponding author:
durlevicstavka3@gmail.com

ORCID ID

Slavka Durlević: 0009-0001-4829-5384

Keywords

ADR regulations
Dangerous goods
Thiophene
Zinc bromate
Comparison
Safety

ABSTRACT

The transport of dangerous goods by road presents a complex safety challenge requiring the implementation of specific procedures defined by ADR regulations. The objective of this paper is to examine, through a comparative analysis of two dangerous goods belonging to different ADR classes-thiophene (UN 2414, Class 3) and zinc bromate (UN 2469, Class 5.1)-whether the ADR classification system adequately reflects fundamental differences in hazard mechanisms and dominant risk scenarios in road transport. Employing a deductive methodological approach, the research systematically analyzes ADR 2025 regulations, identifies specific requirements for each material, and conducts a comparative analysis of safety procedures. Results demonstrate fundamental differences in requirements stemming from opposing hazard mechanisms: thiophene as a fire source requires explosion-proof protection (FL vehicle, Kemler number 33, test pressure 250 kPa), whereas zinc bromate as a combustion intensifier requires stricter vehicle cleanliness control and separation from flammable materials (CV24 provision, SGAV tank, test pressure 100 kPa). Different packing groups (II for thiophene, III for zinc bromate) and transport categories (2 and 3, respectively) reflect varying levels of inherent risk. Comparative analysis identifies key dimensions of differentiation: packaging and containment, electrical protection, vehicle marking, mandatory equipment, and emergency procedures. The scientific contribution of this work is manifested in the systematization and explanation of ADR classification logic through the lens of a concrete case study, providing practical guidelines for transport companies, safety advisors, and all participants in the dangerous goods transport chain.

1. Introduction

Contemporary industrial processes and global trade require continuous transport of chemical materials that pose varying levels of risk to people, property, and the environment. The transport of dangerous goods by road represents a complex challenge demanding the application of detailed safety procedures, constant risk monitoring, and strict adherence to international regulations (Łukasik et al., 2017; Simonavičiūtė et al., 2020). According to data from the European Chemicals Agency, over 110 million tons of dangerous goods are transported annually by road across Europe, constituting approximately 5% of total freight transport (Eurostat, 2021).

The European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR - Accord européen relatif au transport international des marchandises Dangereuses par Route) represents the fundamental legal and technical framework for regulating the transport of dangerous goods (UNECE, 2025). The Agreement was concluded in Geneva on September 30, 1957, under the auspices of the United Nations Economic Commission for Europe (UNECE) and is updated biennially. The currently valid ADR 2025 version entered into force on January 1, 2025, incorporating the latest technological standards and safety procedures.

The Republic of Serbia, as a signatory to the Agreement, fully implements ADR regulations through the Law on Transport of Dangerous Goods ("Official Gazette of RS" No. 104/2016, 83/2018, 95/2018, and 10/2019). ADR classifies dangerous goods into nine basic classes according to their dominant hazardous properties: explosives and articles containing explosives (Class 1), gases (Class 2), flammable liquids (Class 3), flammable solids, self-reactive substances and desensitized explosive solids (Class 4.1), substances liable to spontaneous combustion (Class 4.2), substances which, in contact with water, emit flammable gases (Class 4.3), oxidizing substances (Class 5.1), organic peroxides (Class 5.2), toxic substances (Class 6.1), infectious substances (Class 6.2), radioactive material (Class 7), corrosive substances (Class 8), and miscellaneous dangerous substances (Class 9).

Each class requires specific safety procedures that differ in terms of packaging, vehicle marking, transport conditions, protective equipment, and emergency response protocols. A particular challenge in the transport of dangerous goods is the diversity of their chemical and physical properties, which directly influence risk levels and necessary safety measures (Drégelyi-Kiss et al., 2024). Flammable liquids (Class 3) are characterized by low flash points and rapid evaporation, posing fire and explosion risks, while oxidizing substances (Class 5.1) can significantly intensify combustion upon contact with flammable materials. Understanding these differences is crucial for the proper selection of transport procedures and preventive measures.

The objective of this paper is to examine, through a comparative analysis of two dangerous goods belonging to different ADR classes—thiophene (UN 2414, Class 3) and zinc bromate (UN 2469, Class 5.1)—to what extent the ADR classification system reflects fundamental differences in hazard mechanisms and whether the prescribed safety measures are aligned with the dominant risk scenarios in road transport. The paper aims to demonstrate that ADR requirements are not applied uniformly, but are systematically differentiated based on the physical-chemical properties and primary hazard characteristics of the transported substances.

The scientific contribution of this work is reflected in providing a systematized overview of safety procedures through the lens of comparative analysis of two materials with different hazardous properties, enabling a better understanding of the logic behind the ADR classification system and the practical application of regulations. The research findings may be of significance for transport companies, safety advisors, inspectors, and all participants in the dangerous goods transport chain.

2. Research methodology and adr regulatory framework

2.1. Methodological Approach

The research was conducted through systematic analysis of ADR 2025 regulations (UNECE, 2025) with a focus on safety procedures for transporting thiophene (UN 2414, Class 3) and zinc bromate (UN 2469, Class 5.1). The methodology is based on a deductive approach that entails analyzing regulatory requirements from Table A of ADR Chapter 3.2 and their comparison across the following categories: packaging and containment, labeling and marking, protective equipment, transport conditions, and emergency procedures. Identified requirements were validated against relevant ADR chapters (Parts 4, 5, 7, and 8) to ensure consistency with the overall regulatory framework.

2.2. Analytical framework

The analysis in this paper is based on a structured analytical framework designed to enable a systematic comparison of safety requirements for dangerous goods belonging to different ADR classes. The framework is grounded in the assumption that differences in transport safety measures directly arise from distinct hazard mechanisms rather than from formal classification alone. For each analyzed substance, the following analytical criteria were applied:

- Physical state of the substance;
- Role in the combustion process (fuel or oxidizing agent);
- Primary hazard mechanism;
- Packing group and level of inherent danger;
- Vehicle and tank requirements;
- Electrical protection and equipment requirements;
- Loading and unloading safety measures;
- Compatibility and segregation requirements;
- Transport category and tunnel restrictions.

ADR requirements for thiophene and zinc bromate were examined using these criteria through the analysis of Table A in Chapter 3.2 and relevant provisions from ADR Parts 4, 5, 7, and 8. The application of this analytical framework enables the identification of key differences in safety procedures and supports an assessment of whether the prescribed measures correspond to the dominant risk scenarios associated with each substance.

3. Characteristics and safety procedures for the transportation of thiophene (UN 2414, class 3)

3.1. Physical-Chemical Properties

Thiophene (C₄H₄S) is a heterocyclic aromatic compound containing a five-membered ring with four carbon atoms and one sulfur atom. The molecular mass of thiophene is 84.14 g/mol. At room temperature, thiophene exists as a colorless to slightly yellowish liquid with a characteristic benzene-like odor (UNECE, 2025).

The boiling point of thiophene is 84.1°C, while its melting point is -38.3°C, enabling its application across a wide temperature range. The key characteristic of thiophene from a transport safety perspective is its low flash point of -1°C, which classifies it as a highly flammable liquid (Simonavičiūtė et al., 2020). The relative density of thiophene is 1.065 g/cm³ at 20°C, indicating that thiophene is denser than water. The vapor pressure at 20°C is approximately 80 hPa, indicating significant volatility and evaporation tendency. The explosive limits of thiophene in air range from 1.4% to 12.5% by volume, representing a relatively wide range in which a mixture of thiophene and air can explode. Thiophene exhibits limited solubility in water (approximately 3 g/L at 20°C) but is completely soluble in most organic solvents such as ethanol, ether, benzene, and acetone. These properties are significant in selecting materials for packaging and tanks, as well as in determining procedures in case of spillage or leakage. The chemical reactivity of thiophene is based on its aromatic structure, with the sulfur atom contributing significantly to π -electron delocalization. Thiophene undergoes electrophilic substitution reactions and is more reactive than benzene. At high temperatures or in the presence of catalysts, thiophene can react with hydrogen to form butane and hydrogen sulfide (H₂S). This reaction forms the basis of the hydrodesulfurization process used in the petroleum industry to remove sulfur compounds from fuels (Łukasik et al., 2017). The fundamental physicochemical properties of thiophene affecting transport safety are presented in Table 1.

Table 1. Key Physical-Chemical Properties of Thiophene

Parameter	Value
Molecular formula	C ₄ H ₄ S
Molecular mass	84,14 g/mol
Flash point	-1°C
Boiling temperature	84,1°C
Relative density	1,065 g/cm ³ (20°C)
Explosive limits	1,4% - 12,5% vol.

3.2. Classification and identification according to ADR 2025

According to Table A of Chapter 3.2 of the ADR 2025 regulation, thiophene is identified by the following parameters shown in Table 2 (UNECE, 2025). In column (1) - UN number: 2469; column (2) the proper shipping name is ZINC BROMATE; column (3a) indicates the hazard class: 5.1 (Oxidizing substances); column (3b) assigns the classification code: O2. Classification code O2 designates that zinc bromate belongs to the subgroup of solid oxidizing substances without additional (subsidiary) hazards. Column (4) defines the packing group: III (substances with a low degree of danger). Packing group III indicates substances with a low degree of danger, which is less stringent compared to packing group II (thiophene) or group I, which encompasses the most dangerous substances (Łukasik et al., 2017).

Table 2. ADR Classification Parameters for Thiophene (ADR 2025, Tom I)

Column	Parameter (ADR 3.2)	Value for Thiophene (UN 2414)
(1)	UN number	2414
(2)	Name and description	TIOFEN
(3a)	Class	3
(3b)	Classification code	F1
(4)	Packaging group	II
(5)	Hazard labels	3
(6)	Special provisions	-
(7a)	Limited quantity	1 L
(7b)	Exempt quantity	E2
(8)	Packaging instructions	P001, IBC02, R001
(9a)	Special packaging provisions	-
(9b)	Provisions for joint packaging	MP19
(10)	Instructions for portable tanks	T4
(11)	Special provisions for tanks	TP1
(12)	Tanker codes	LGBF
(13)	Special provisions for ADR tanks	-
(14)	Tanker transport vehicles	FL
(15)	Transport category (tunnels)	2 (D/E)
(16)	Special provisions - packages	-
(17)	Special provisions - bulk cargo	-
(18)	Special provisions - loading/unloading	-
(19)	Special provisions for work	S2, S20
(20)	Hazard identification number	33

Column (5) hazard label: 5.1 (yellow label with flame above circle). Column (6), which determines special provisions in case of zinc bromate transport, indicates that no special provisions exist. The limited quantity for zinc bromate is 5 kg in column (7a), meaning that packages containing up to 5 kilograms can be transported under relaxed conditions without applying all strict ADR requirements. Code E1 in column (7b) indicates that the material is exempt from certain packaging and marking requirements when transported in small quantities. According to column (8) of Table A, the following packing instructions are prescribed for zinc bromate (UNECE, 2025): P002 - Packing instruction for solid substances allowing the use of combination, single, and composite packagings. The maximum net mass for packing group III is up to 400 kg for combination packagings (outer packagings: steel, aluminum, plastic, plywood, or fiberboard drums; inner packagings: glass, plastic, or metal receptacles up to 50 kg). Single packagings include steel or aluminum drums, plastic drums, jerricans, and boxes of various materials. IBC08 - Instruction for intermediate bulk containers (IBC) allowing the use of metal IBCs (codes 11A, 11B, 11N, 21A, 21B, 21N, 31A, 31B, 31N), rigid plastic IBCs (11H1, 11H2, 21H1, 21H2, 31H1, 31H2).

Composite IBCs (11HZ1, 11HZ2, 21HZ1, 21HZ2, 31HZ1), as well as fiberboard IBCs (11G), wooden IBCs (11C, 11D, 11F), and flexible IBCs. Special packing provisions in column (9a) - (B3): Flexible IBCs must be sift-proof and water-resistant or must be fitted with a water-resistant liner. This is particularly important for zinc bromate, which is soluble in water. MP10 column (9b) - The mixed packing provision stipulates that zinc bromate may be packed together with other substances from the same class (with different classification codes) or with substances from other classes, but only in quantities up to 5 kg per inner packaging, provided no dangerous reaction occurs between the substances.

For transport of zinc bromate in tanks, the following parameters are prescribed (UNECE, 2025): T1 column (10) - Instruction for portable tanks with a minimum test pressure of 150 kPa (1.5 bar). Portable tanks must be constructed from materials resistant to the corrosive action of zinc bromate. TP33 column (11) - Special tank provision relating to granular and powdery solid substances. This code prescribes that the tank must be adapted for transporting substances in a solid state. SGAV column (12) - Tank code (Solid, Granular, Average hazard) designates tanks for solid granular substances with an average degree of hazard. This code prescribes specific technical requirements for the construction of tanks intended for transporting zinc bromate. TU3 column (13) - Special provision for ADR tanks prescribing additional safety requirements specific to oxidizing substances. AT column (14) - Vehicle designation (A - temperature, T - tank) indicates a vehicle with a tank for transport at normal temperatures.

The vehicle must be equipped with fire extinguishers with a minimum capacity of 12 kg in accordance with standard EN 3. Transport category (3) column (15) - from Table A of Chapter 3.2 indicates that for zinc bromate transport, passage through category E tunnels is prohibited, while passage through category A, B, C, and D tunnels is permitted, regardless of whether a tank or other transport vehicle is used. Codes VC1 and VC2 in column (17) have the following meanings: Transport in bulk in sheeted vehicles, sheeted containers, or sheeted bulk containers is permitted; Transport in bulk in closed vehicles, closed containers, or closed bulk containers is permitted.

Code CV24 in column (18) stipulates that before loading, vehicles and containers must be thoroughly cleaned and must be particularly free from combustible residues (straw, hay, paper, etc.). The use of readily combustible materials for stowing packages is prohibited. The hazard identification number 50 in column (20) represents an oxidizing substance with the ability to intensify combustion.

3.3. Marking of transport units

In Figure 1, two methods of tank vehicle marking are presented. The first method involves placing two empty orange plates (dimensions 40 × 30 cm, without hazard identification numbers or UN numbers) on the front and rear sides of the tank vehicle. Two filled orange plates (dimensions 40 × 30 cm), with the Kemler code 33 displayed in the upper section and the UN number 2414 in the lower section, are mounted on the lateral sides of the tank vehicle. Hazard labels (with minimum dimensions of 25 × 25 cm) are placed adjacent to the filled orange plates on the lateral sides of the tank vehicle, as well as on the rear side next to the empty orange plate. In this case, the applicable hazard label for UN 2414 corresponds to Class 3. Class 3 hazard labels are red in color, featuring a black flame symbol and the number “3” in the lower corner, as illustrated in Figure 1.

The second method of tank vehicle marking involves placing filled orange plates (dimensions 40 × 30 cm), displaying the Kemler code 33 in the upper section and the UN number 2414 in the lower section, on the front and rear sides of the tank vehicle. Hazard labels (with minimum dimensions of 25 × 25 cm) are mounted on the lateral sides of the tank vehicle and on the rear side, adjacent to the orange plate. All markings must be made of reflective material resistant to atmospheric conditions, be legible from a distance of at least 30 meters, and remain firmly attached even in the event of a fire for at least the first 15 minutes (UNECE, 2025). Vehicles transporting thiophene must be marked in the following manner, which will be shown in Figure 1.

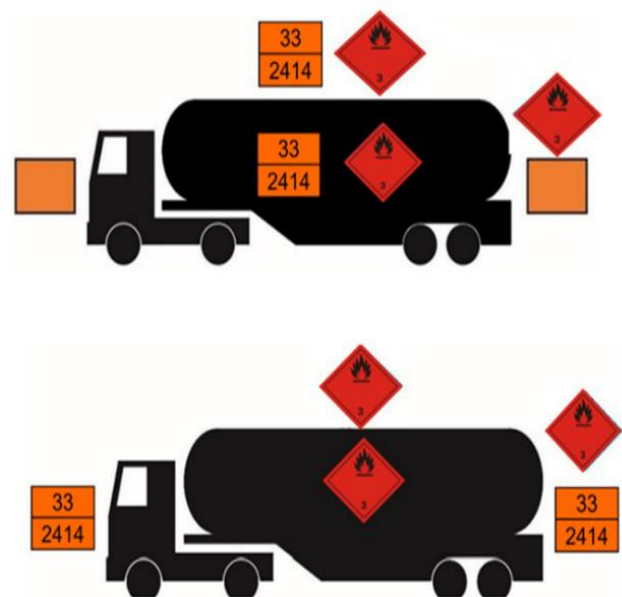


Figure 1. Both ways of marking tanks when transporting Thiophene (UN 2414)

3.4. Mandatory equipment for transporting thiophene

Each vehicle transporting thiophene must be equipped with the following equipment (columns 16–19). General equipment for each transport unit includes: two self-standing warning signs (reflective triangles or warning lights); one high-visibility vest for each crew member (in accordance with EN ISO 20471); a portable explosion-proof lamp (in accordance with ADR provision 8.3.4); one pair of chemical-resistant protective gloves; and eye protection equipment (safety goggles or a face shield). Additional equipment specific to Class 3 (in accordance with codes S2 and S20) includes: one shovel for removing spilled material; one drain cover (minimum dimensions 60 cm × 60 cm) to prevent the entry of thiophene into the drainage system; one collecting container for minor leakages; and fire extinguishers with a minimum total capacity of 12 kg for the vehicle and 6 kg for the load. Personal protective equipment: For thiophene, the use of a protective mask is not mandatory, as it does not belong to Class 2.3 (toxic gases) or Class 6.1 (toxic substances). However, the use of a respirator equipped with a combined A1B1-type filter is recommended in the event of significant leaks or spills.

3.5. Critical points in the safe transport of thiophene

The analysis of ADR requirements for thiophene identifies the following critical points: Fire and explosion hazard – The low flash point (–1 °C) makes thiophene hazardous even at low ambient temperatures. Thiophene vapors can travel to distant ignition sources and cause flashback ignition. Vapor concentrations in the range of 1.4% to 12.5% form an explosive atmosphere. Electrostatic charging – Thiophene is a poor electrical conductor, which may lead to the accumulation of static electricity during tank loading and unloading operations. Proper grounding is mandatory before all transfer operations. Compatibility with other materials – Thiophene must not come into contact with strong oxidizing agents (Class 5.1 substances, such as zinc bromate), as violent reactions may occur. Additionally, metals such as aluminum and magnesium may react with thiophene at elevated temperatures. Environmental impact – The release of thiophene into water bodies may be harmful to aquatic organisms. Thiophene is not readily biodegradable and may persist in the environment. Preventing entry into sewage systems and natural watercourses is therefore mandatory (Simonavičiūtė et al., 2020). Health effects – Inhalation of thiophene vapors may cause respiratory tract irritation, headache, nausea, and dizziness. Skin contact may result in irritation. Prolonged exposure may have adverse effects on the central nervous system.

4. Characteristics and safety procedures for the transportation of zinc bromate (UN 2469)

4.1. Physico-chemical characteristics of zinc bromate

Zinc bromate, identified by UN number 2469, is a chemical compound used in various industrial processes. This substance consists of zinc and bromine atoms, forming a stable and well-defined molecular structure, $Zn(BrO_3)_2$, with a molecular mass of 321.20 g/mol (UNECE, 2025). Zinc bromate is commonly applied in galvanic metal protection, electrochemical processes, and as a catalyst in certain chemical reactions. It appears as a white or colorless crystalline powder that is soluble in water and may be used as a source of bromate ions in chemical reactions and processes. As a chemical compound classified under Class 5.1 according to the ADR classification, zinc bromate exhibits oxidizing properties (Drégelyi-Kiss et al., 2024). This means that it can increase the risk of ignition and fire due to its ability to support the combustion of other materials. The primary hazard associated with Class 5.1 substances is the promotion of combustion. Zinc bromate can intensify fires when it comes into contact with flammable materials. Unlike Class 3 flammable substances, which burn independently, oxidizing substances such as zinc bromate do not burn on their own but significantly enhance the combustion intensity of other materials upon contact (Simonavičiūtė et al., 2020). This fundamental difference directly affects all safety procedures during transport.

Table 3. Key Physical-Chemical Properties of zinc bromate

Parameter	Value
Molecular formula	$Zn(BrO_3)_2$
Molecular mass	321,20 g/mol
Physical state	White crystalline powder
Solubility in water	Dissolved
Features	Oxidizing agent
The main danger	Supports combustion

4.2. Safety procedures according to ADR Table A (Chapter 3.2)

According to Table A of Chapter 3.2 of the ADR 2025 regulation, zinc bromate is classified by the following parameters, shown in Table 4. In column (1), the UN number is 2469; column (2) specifies the proper shipping name as ZINC BROMATE; column (3a) defines the hazard class as 5.1 (oxidizing substances), while column (3b) assigns the classification code O2, indicating that zinc bromate belongs to the subgroup of solid oxidizing substances without subsidiary hazards. Column (4) specifies the packing group as III (substances presenting a low degree of danger), which is less stringent compared to Packing Group II (thiophene) or Packing Group I, which includes the most hazardous substances (Łukasik et al., 2017).

Table 4. Key Physical-Chemical Properties of zinc bromate (ADR 2025, Tom I)

Column	Parameter (ADR 3.2)	Value for Zinc Bromate (UN 2469)
(1)	UN number	2469
(2)	Name and description	CINK-BROMAT
(3a)	Class	5.1
(3b)	Classification code	O2
(4)	Packaging group	III
(5)	Hazard labels	5.1
(6)	Special provisions	-
(7a)	Limited quantity	5 kg
(7b)	Exempt quantity	E1
(8)	Packaging instructions	P002, IBC08, LP02, R001
(9a)	Special packaging provisions	B3
(9b)	Provisions for joint packaging	MP10
(10)	Instructions for portable tanks	T1
(11)	Special provisions for tanks	TP33
(12)	Tanker codes	SGAV
(13)	Special provisions for ADR tanks	TU3
(14)	Tanker transport vehicles	AT
(15)	Transport category (tunnels)	3 (E)
(16)	Special provisions - packages	-
(17)	Special provisions - bulk cargo	VC1, VC2
(18)	Special provisions - loading/unloading	CV24
(19)	Special provisions for work	-
(20)	Hazard identification number	50

Column (5) indicates the hazard label 5.1 (yellow label with a flame above a circle). Column (6) shows that no special provisions apply to the transport of zinc bromate. The limited quantity specified in column (7a) is 5 kg, meaning that packages containing up to 5 kg may be transported under simplified conditions without applying all ADR requirements, while the E1 code in column (7b) indicates an exemption from certain packaging and marking requirements when transported in small quantities. According to column (8) of Table A, the applicable packing instructions are P002, which allows the use of combination, single, and composite packagings with a maximum net mass of up to 400 kg for Packing Group III, and IBC08, which permits the use of metal, rigid plastic, composite, fiberboard, wooden, and flexible intermediate bulk containers (UNECE, 2025). Column (9a) specifies special packing provision B3, requiring flexible IBCs to be sift-proof and water-resistant or equipped with a waterproof inner liner, which is particularly important due to the water solubility of zinc bromate, while column (9b).

MP10, regulates mixed packing, allowing zinc bromate to be packed together with other substances of the same class or with substances of other classes in quantities of up to 5 kg per inner packaging, provided that no dangerous reaction occurs. For the transport of zinc bromate in tanks, column (10) prescribes T1 portable tank instructions with a minimum test pressure of 150 kPa (1.5 bar), column (11) specifies special provision TP33 for granular and powdery solids, column (12) assigns the tank code SGAV for solid granular substances with an average hazard level, column (13) defines special tank provision TU3 for oxidizing substances, and column (14) indicates the AT vehicle code for tank transport at ambient temperature, requiring vehicles to be equipped with fire extinguishers with a minimum total capacity of 12 kg in accordance with EN 3. The transport category E in column (15) indicates that passage through Category E tunnels is prohibited, while transit through Categories A, B, C, and D is permitted regardless of the transport unit. The codes VC1 and VC2 in column (17) allow bulk transport in sheeted or closed vehicles and containers, while the CV24 code in column (18) requires that vehicles and containers be thoroughly cleaned before loading and be free from flammable residues, prohibiting the use of highly flammable materials for load securing. Finally, the hazard identification number 50 in column (20) denotes an oxidizing substance capable of intensifying combustion.

4.3. Marking of transport units

Vehicles transporting zinc bromate must be marked in the following manner, which will be shown in Figure 2. In Figure 2, two methods of tank vehicle marking are presented. In the first method, two empty orange plates (dimensions 40 × 30 cm, without hazard identification numbers or UN numbers) are placed on the front and rear sides of the tank.

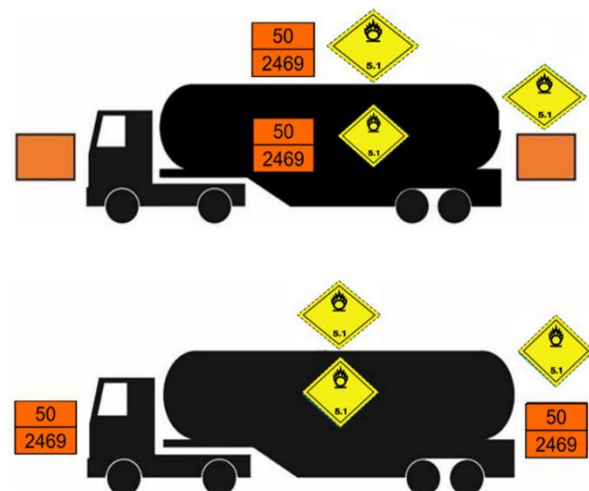


Figure 2. Both ways of marking tanks when transporting zinc bromate (UN 2469)

Two filled orange plates (dimensions 40 × 30 cm), with the Kemler code 50 displayed in the upper section and the UN number 2469 in the lower section, are mounted on the lateral sides of the tank. Hazard labels (with minimum dimensions of 25 × 25 cm) are positioned adjacent to the filled orange plates on the lateral sides of the tank and on the rear side next to the empty orange plate. In this case, the applicable hazard label for UN 2469 is Class 5.1. Hazard labels of Class 5.1 are yellow in color, featuring a black flame symbol and the number “5.1” in the lower corner, as shown in Figure 2. The second method of tank vehicle marking involves placing filled orange plates (dimensions 40 × 30 cm), with the Kemler code 50 in the upper section and the UN number 2469 in the lower section, on the front and rear sides of the tank, while hazard labels (minimum dimensions 25 × 25 cm) are placed on the lateral sides of the tank and on the rear side adjacent to the orange plate. All markings must be made of reflective material resistant to atmospheric conditions, be legible from a distance of at least 30 meters, and remain securely affixed even in the event of a fire during the first 15 minutes (UNECE, 2025).

4.4. Mandatory equipment for transporting zinc bromate

Each vehicle transporting zinc bromate must be equipped with the following equipment (UNECE, 2025): General equipment for each transport unit, including two self-standing warning signs (reflective triangles or warning lights), one high-visibility vest for each crew member in accordance with EN ISO 20471, a portable explosion-proof lamp in accordance with ADR provision 8.3.4, one pair of chemical-resistant protective gloves, and eye protection equipment (safety goggles or a face shield); Additional equipment specific to Class 5.1 (in accordance with code CV24), including one shovel for removing spilled material, one drain cover with minimum dimensions of 60 cm × 60 cm, one collecting container for minor leakages, and fire extinguishers with a minimum total capacity of 12 kg for the vehicle and 6 kg for the load.

4.5. Critical points in the safe transport of zinc bromate

The analysis of ADR requirements for zinc bromate identifies the following critical points (Simonavičiūtė et al., 2020): the risk of combustion intensification, as zinc bromate, being an oxidizing substance, does not burn by itself but can significantly enhance the combustion of other materials, and contact with flammable materials such as wood, paper, textiles, or flammable liquids may lead to violent reactions and rapid fire spread; incompatibility with other materials, as zinc bromate must not come into contact with flammable substances of Class 3 (such as thiophene), organic materials, reducing agents, or strong acids, since the combination of an oxidizing substance (Class 5.1).

A flammable substance (Class 3) may be explosive; vehicle and equipment cleanliness, as required by provision CV24, which mandates that vehicles be completely cleaned of all flammable residues prior to loading zinc bromate, given that even small amounts of combustible material may pose a risk when in contact with an oxidizing substance; environmental impact, since spills of zinc bromate may be harmful to the environment due to the presence of bromine compounds, making it mandatory to prevent entry into sewage systems and natural watercourses; and health effects, as contact with skin or eyes may cause irritation and inhalation of zinc bromate dust may lead to respiratory tract irritation, necessitating the use of appropriate personal protective equipment.

5. Comparative analysis of thiophene and zinc bromate safety procedures

A systematic analysis of ADR regulations for thiophene (UN 2414, Class 3) and zinc bromate (UN 2469, Class 5.1) reveals fundamental differences in safety procedures arising from the opposing physicochemical properties of these substances. A comparative approach enables the identification of key dimensions in which transport requirements differ, as well as an understanding of the rationale underlying the ADR classification system.

The basic dichotomy between these two substances is rooted in their roles in the combustion process. Thiophene, as a flammable liquid, represents a fuel that can act as a source of fire, whereas zinc bromate, as an oxidizing substance, represents a source of oxygen that can dramatically intensify a fire initiated by another material. This fundamental difference decisively shapes all aspects of transport procedures. For thiophene, safety measures are focused on preventing contact with ignition sources (sparks, flames, high-temperature surfaces), while for zinc bromate, measures are directed toward preventing contact with flammable materials, which, in the presence of an oxidizing substance, could trigger uncontrolled and intensified combustion.

Classification into different packing groups (thiophene in Packing Group II and zinc bromate in Packing Group III) reflects different levels of inherent hazard. Thiophene, with a flash point below 23 °C, belongs to a group with a medium degree of danger and requires stricter packaging measures with a test pressure of 250 kPa. Zinc bromate, despite its oxidizing nature, is classified in the lowest hazard group and is subject to less stringent requirements with a test pressure of only 100 kPa. This difference arises from the fact that thiophene is a volatile liquid capable of forming explosive mixtures with air, whereas zinc bromate is a stable solid substance that does not pose an immediate hazard in the absence of flammable materials.

Requirements for vehicle electrical protection represent a critical point of differentiation. The transport of thiophene requires an FL vehicle equipped with explosion-proof electrical installations and electrostatic protection, whereas the transport of zinc bromate permits the use of a standard AT vehicle without special explosion-proof characteristics. This distinction directly results from the risk of explosive vapor formation in the case of thiophene, which may be initiated by an electrical spark. The Kemler codes (33 for thiophene and 50 for zinc bromate) condense these differences into simple numerical designations that enable rapid identification of the primary hazard.

Of particular significance is the CV24 requirement applicable to zinc bromate, which mandates thorough cleaning of vehicles to remove flammable residues before loading. This requirement has no direct parallel in procedures for thiophene transport, where the focus is on preventing leakage and evaporation rather than vehicle cleanliness with respect to combustible materials. Paradoxically, an oxidizing substance that does not burn itself requires stricter vehicle cleanliness rules than a flammable liquid, clearly illustrating the difference in hazard mechanisms. The presence of even small quantities of flammable residues (straw, paper, wood debris) on a vehicle may, in combination with zinc bromate, lead to violent reactions.

Tank codes represent another dimension of differentiation. Thiophene requires the use of an LGBF tank (Liquid, Greater than 60 °C flash point, Flammable), whereas zinc bromate requires an SGAV tank (Solid, Granular, Average hazard). This difference reflects not only the physical state of the substances (liquid versus solid) but also specific engineering requirements. An LGBF tank must be designed to retain liquids under pressure with dedicated ventilation systems, whereas an SGAV tank must be adapted for the transport of granular solid materials with appropriate systems to prevent dust formation.

Transport categories indicate a moderate difference in overall risk assessment. Thiophene is classified in transport category 2 with tunnel code D/E, indicating a significant but not extreme risk, whereas zinc bromate is classified in transport category 3 with tunnel code E, indicating a somewhat lower level of risk. Both substances are prohibited in Category E tunnels, but for different reasons: thiophene due to the risk of fire and explosion in confined spaces, and zinc bromate due to the potential intensification of fire in the event of an incident within a tunnel. Mandatory equipment requirements for both substances include common elements such as fire extinguishers, crew protective gear, and warning signs, but there are critical differences in specifications. Transporting thiophene requires an EX/III explosion-proof lamp, while a standard portable lamp is enough for zinc bromate.

Conversely, zinc bromate transport demands additional equipment for cleaning and collecting spilled material—like a shovel, drain cover, and collecting container, which are not required for thiophene, again highlighting the fundamentally different hazard mechanisms. Table 5 presents the basic differences between thiophene (class 3) and zinc bromate (class 5.1).

Table 5. Comparative overview of safety requirements for the transport of thiophene and zinc bromate according to ADR 2025

Criterion	Thiophene (UN 2414, Class 3)	Zinc Bromate (UN 2469, Class 5.1)
Physical state	Liquid	Solid (crystalline powder)
Role in combustion process	Fuel – source of fire	Oxidizing agent – intensifies combustion
Packing group	II – medium danger	III – low danger
Flash point	-1 °C	Not applicable
Primary hazard	Fire and explosion of vapors	Intensification of fire in contact with combustible materials
Hazard identification number (Kemler code)	33	50
Vehicle type	FL vehicle	AT vehicle
Electrical equipment requirements	Explosion-proof (EX)	Standard
Tank code	LGBF	SGAV
Key loading/unloading requirements	Grounding, prevention of electrostatic discharge	Mandatory vehicle cleanliness (CV24)
Compatibility with other substances	Incompatible with oxidizing substances	Incompatible with flammable substances
Transport category (tunnel restrictions)	Category 2 (D/E)	Category 3 (E)
Focus of safety measures	Prevention of ignition and leakage	Prevention of contamination and contact with combustible residues

6. Conclusion

This paper analyzed safety procedures for the road transport of two dangerous goods belonging to different ADR classes: thiophene (UN 2414, Class 3) and zinc bromate (UN 2469, Class 5.1). The conducted analysis confirms that ADR regulations are structured in a manner that enables precise differentiation of safety requirements in accordance with the dominant hazard mechanism of each substance, rather than applying uniform measures to all dangerous goods. The results indicate that effective risk control in the transport of dangerous goods requires a clear understanding of the fundamental differences between flammable substances and oxidizing agents. Improper application of safety procedures or inadequate knowledge of incompatibilities between substances may lead to increased risk during transport, particularly in situations involving combined loading, insufficient vehicle preparation, or emergency response.

The practical value of this research lies in its applicability to transport companies, dangerous goods safety advisors, inspectors, and ADR driver training programs. The comparative approach presented in this paper may serve as a practical tool to improve internal transport procedures, enhance risk awareness, and support decision-making on the selection of appropriate transport conditions for different classes of dangerous goods. A limitation of this study is its reliance on normative analysis of ADR 2025 regulations without the inclusion of empirical data such as accident statistics, incident reports, or experimental risk assessments. Future research could expand the scope of this work by incorporating real transport accident data, quantitative risk assessment methods, or simulation-based analyses to further validate and strengthen the conclusions presented.

- [8] UNECE. (2025). European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR) 2025. ECE/TRANS/352, Vols. I and II. United Nations. <https://unece.org/transport/dangerous-goods/about-adr>
- [9] Zakon o transportu opasne robe. (2016, 2018, 2019). Službeni glasnik Republike Srbije, br. 104/2016, 83/2018, 95/2018, 10/2019.

References

- [1] Batarliene, N. (2020). Essential safety factors for the transport of dangerous goods by road: A case study of Lithuania. *Sustainability*, 12(12), 4954. <https://doi.org/10.3390/su12124954>
- [2] Di Fazio, A., Bettinelli, D., Louette, E., Mechin, J. P., Zazza, M., Vecchiarelli, P., & Domanico, L. (2016). European pathways to introduce EGNOS and Galileo for dangerous goods transport. *Transportation Research Procedia*, 14, 1482-1491. <https://doi.org/10.1016/j.trpro.2016.05.222>
- [3] Drégelyi-Kiss, Á., Tóth, G. N., Horváth, A., & Farkas, G. (2024). Risk management in the transport of dangerous goods in Hungary: A statistical and FMEA-based case study on bitumen transportation. *J. Eng. Manag. Syst. Eng*, 3(4), 236-247. <https://doi.org/10.56578/jemse030405>
- [4] Eurostat. (2021). Road freight transport of dangerous goods by type of goods. European Commission. https://ec.europa.eu/eurostat/statistics-explained/index.php/Road_freight_transport_by_type_of_goods
- [5] Łukasik, Z., Kuśmińska-Fijałkowska, A., & Kozyra, J. (2017). *Transport of dangerous goods by road from a European aspect*. *Zeszyty Naukowe. Transport/Politechnika Śląska*. <http://dx.doi.org/10.20858/sjsutst.2017.95.11>
- [6] Ministry of Construction, Transport, and Infrastructure. (2025). ADR 2025 Tom 1: Agreement concerning the International Carriage of Dangerous Goods by Road [PDF]. Government of the Republic of Serbia. https://www.mgsi.gov.rs/sites/default/files/adr_2025_tom_1.pdf
- [7] Ministry of Construction, Transport, and Infrastructure. (2025). ADR 2025 Tom 2: Agreement concerning the International Carriage of Dangerous Goods by Road [PDF]. Government of the Republic of Serbia. https://www.mgsi.gov.rs/sites/default/files/adr_2025_tom_2.pdf