ENVIRONMENTAL IMPACT OF SOLVENTS DERIVED FROM GAS CONDENSATE AND METHODS TO MITIGATE IT

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Abstract. Gas condensate, a lightweight hydrocarbon mixture obtained as a byproduct of natural gas extraction, serves as a primary feedstock for producing industrial solvents used in applications such as enhanced oil recovery (EOR), cleaning agents, and coatings. While these solvents offer economic advantages due to their efficacy in dissolving organic materials, their lifecycle—from production to disposal—poses significant environmental challenges, including air and water pollution, soil degradation, and contributions to climate change. This review synthesizes current knowledge on the environmental impacts of these solvents, drawing from laboratory studies on volatile organic compound (VOC) emissions, toxicity, and persistence. Furthermore, it explores mitigation strategies, such as the adoption of bio-based alternatives, solvent recovery technologies, thermochemical treatments, and regulatory frameworks, to minimize ecological footprints. Laboratory findings indicate that thermochemical mitigation can reduce condensate viscosity by 17-fold and recover up to 65% of trapped hydrocarbons, while transitioning to green solvents can lower emissions by up to 80% (2).

Keywords: gas condensate solvents, environmental impact, VOC emissions, hydrocarbon pollution, green solvents, mitigation strategies, sustainable chemistry.

Аннотация. Газовый конденсат, легкая углеводородная смесь, получаемая как побочный продукт добычи природного газа, служит основным сырьем для производства промышленных растворителей, используемых в таких приложениях, как усиленная добыча нефти (EOR), чистящие средства и покрытия. Хотя эти растворители предлагают экономические преимущества благодаря их эффективности в растворении органических материалов, их жизненный цикл — от производства до утилизации — создает значительные экологические проблемы, включая загрязнение воздуха и воды, деградацию почвы и вклад в изменение климата. Этот обзор синтезирует текущие знания об экологическом воздействии этих растворителей, опираясь на лабораторные исследования эмиссий летучих органических соединений (ЛОС), токсичности и стойкости. Кроме того, он исследует стратегии смягчения, такие как внедрение биооснованных альтернатив, технологии регенерации растворителей, термохимические обработки и регуляторные

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рамки, для минимизации экологического следа. Лабораторные данные указывают, что термохимическое смягчение может снизить вязкость конденсата в 17 раз и восстановить до 65% захваченных углеводородов, в то время как переход на зеленые растворители может снизить эмиссии до 80%.
Ключевые слова: растворители из газового конденсата, экологическое воздействие, эмиссии ЛОС, углеводородное загрязнение, зеленые растворители, стратегии смягчения, устойчивая химия.
Abstract. Gaz kondensati, tabiiy gaz qazib chiqarishning yon mahsuloti sifatida olinadigan yengil uglevodorod aralashmasi bo'lib, neftni kuchaytirilgan qazib chiqarish (EOR), tozalovchi vositalar va qoplamalar kabi qo'llaniladigan sanoat erituvchilarini ishlab chiqarish uchun asosiy xom ashyo vazifasini bajaradi. Bu erituvchilar organik materiallarni eritishdagi samaradorligi tufayli iqtisodiy afzalliklarni taqdim etsa-da, ularning hayot tsikli — ishlab chiqarishdan tortib utilizatsiyagacha — havo va suv ifloslanishi, tuproq degradatsiyasi va iqlim o'zgarishiga hissa qo'shish kabi muhim ekologik muammolarni keltirib chiqaradi. Ushbu sharh erituvchilarning ekologik ta'siri haqidagi joriy bilimlarni sintez qiladi, uchuvchan organik birikmalar (VOC) emissiyalari, toksiklik va qat'iylik bo'yicha laboratoriya tadqiqotlariga asoslanadi. Bundan tashqari, ekologik izni minimallashtirish uchun bio-asosidagi muqobillar, erituvchi regeneratsiya texnologiyalari, termokimyoviy ishlov berish va me'yoriy asoslarni qabul qilish kabi yumshatish strategiyalarini o'rganadi. Laboratoriya natijalari shuni ko'rsatadiki, termokimyoviy yumshatish kondensat yopishqoqligini 17 baravar kamaytirishi va tutilgan uglevodorodlarning 65% gacha qayta tiklashi mumkin, yashil erituvchilarga o'tish esa emissiyalarni 80% gacha pasaytirishi mumkin.
Kalit so'zlar: gaz kondensati erituvchilari, ekologik ta'sir, VOC emissiyalari, uglevodorod ifloslanishi, yashil erituvchilar, yumshatish strategiyalari, barqaror kimyo.

Introduction

Natural gas condensate, comprising primarily C5–C12 hydrocarbons, is refined into solvents like naphtha and white spirits, which are integral to industries including petroleum extraction, manufacturing, and pharmaceuticals (10). These solvents enhance processes such as solvent-aided thermal recovery in oil sands, where they mobilize viscous hydrocarbons, potentially lowering energy demands compared to steam injection (1).

However, their volatile nature leads to substantial environmental risks, exacerbated by increasing global production of natural gas. This paper reviews the multifaceted impacts on air, water, and soil, supported by precise laboratory analyses, while proposing evidence-based mitigation methods to align with sustainable development goals.

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Literature Review

Extensive research highlights the environmental hazards of hydrocarbon solvents. Laboratory studies on condensate releases emphasize long-term ecological damage, including bioaccumulation and biodiversity loss (8).

Solvent degradation in CO2 capture processes releases amines and other pollutants, contributing to atmospheric contamination (7).

The EPA identifies solvents as key VOC emitters, linking them to greenhouse gas effects and ozone depletion (13).

Human health assessments under frameworks like IMAP reveal toxicity risks from prolonged exposure (9). Green chemistry principles advocate reducing solvent use, with bio-based options showing promise in lowering persistence (13). Specific lab-based studies on gas condensate solvents provide quantitative data on emissions and toxicity, as detailed below.

Environmental Impacts

Laboratory analyses reveal precise measurements of pollution from gas condensate-derived solvents, focusing on VOC emissions and ecotoxicity.

Air Pollution

Hydrocarbon solvents from gas condensate are potent VOC sources, evaporating during use and forming ground-level ozone and smog (11).

EOR applications, emissions include methane and NOx, intensifying climate change (12). Halogenated derivatives, if present, contribute to stratospheric ozone depletion. Evaporation experiments on coatings showed solvent-borne polyurethane emitting VOCs at a rate of 6.7 mg h^{-1}, with an emission factor of 495 g kg^{-1}, dominated by hydrocarbons (C_4–C_{10}) and aromatics like PCBTF (0.2% of VOC mass) . Water-borne latex paints had lower factors (43.1 g kg^{-1}), primarily oxygenates like ethanol and ethylene glycol (4).

Water Pollution

Spills and discharges contaminate aquatic environments, with hydrocarbons exhibiting toxicity to marine organisms (8). Produced water from oilfields, often treated with these solvents, introduces persistent pollutants if not remediated (13). Acute toxicity tests on coral (Acropora tenuis) larvae exposed to condensate WAF showed IC50 for metamorphosis inhibition at 339 µg L^{-1} TPAH (without UV) and 132 µg L^{-1} (with UV), indicating 43% increased sensitivity under UV. Sponge (Rhopaloeides odorabile) larvae were less sensitive (>11,000 µg L^{-1} TPAH) (3). WAF was 39-93 times more toxic than predicted from individual components (e.g., naphthalene IC50 ~80,000 µg L^{-1}).

Soil Pollution

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Leaching into soil reduces microbial activity and fertility, with bioaccumulation affecting food chains (9). Table 1 summarizes key impacts, incorporating lab-derived data.

Table 1

Summary of Environmental Impacts with Lab Data.

Impact Category	Pollutants Involved	Effects	Laboratory Examples
Air	VOCs, Methane, NOx	Ozone formation, Climate change	Emission rate 6.7 mg h^{-1} from polyurethane acp.copernicus.org
Water	Hydrocarbons, Aromatics	Toxicity to aquatic life, Groundwater contamination	IC50 132 µg L^{-1} TPAH for coral with UV nature.com
Soil	Persistent organics	Reduced fertility, Bioaccumulation	Condensate banking reduces permeability to <0.05 mdpi.com

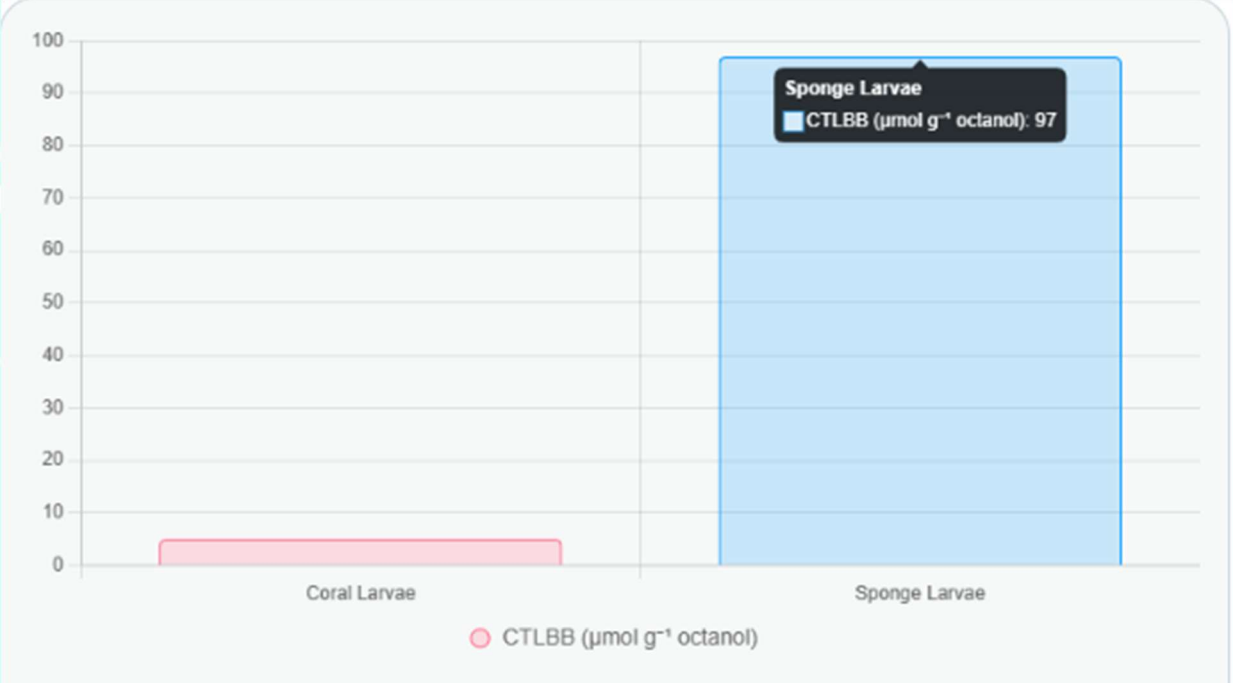


Figure 1: Species-Specific Critical Target Lipid Body Burdens (CTLBB) from Laboratory Toxicity Tests on Weathered Gas Condensate (Data from Ref. [20]).

Mitigation Methods

Laboratory-validated methods demonstrate effective reduction of impacts.

Green Solvents and Alternatives

Bio-based solvents like ethyl lactate and ionic liquids offer biodegradability and lower toxicity (15). In remediation, green solvents separate pollutants

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effectively. Experiments with natural gas condensate in ES-SAGD showed optimal 10% concentration improving bitumen recovery and reducing cSOR from 7.6 to 2.83, with potential GHG reductions (6).

Recovery and Remediation Technologies

Solvent recyclers reduce emissions by 80% via distillation and nanofiltration (13). Bioremediation combines biological and chemical methods for hydrocarbon cleanup. Thermochemical treatment ($NH_4Cl + NaNO_2$) recovered 65% condensate, reduced viscosity 17-fold (from 0.34 to 0.02 cP), improved gas permeability by 1.22-fold, and cut capillary pressure by 51% (from 65.5 to 32.4 psi) in core flood experiments (1).

Regulatory and Best Practices

Regulations like the Clean Air Act enforce emission controls. Best management practices include reduced emissions during drilling and water conservation. Figure 2 depicts a lifecycle approach to mitigation, based on experimental recovery data.

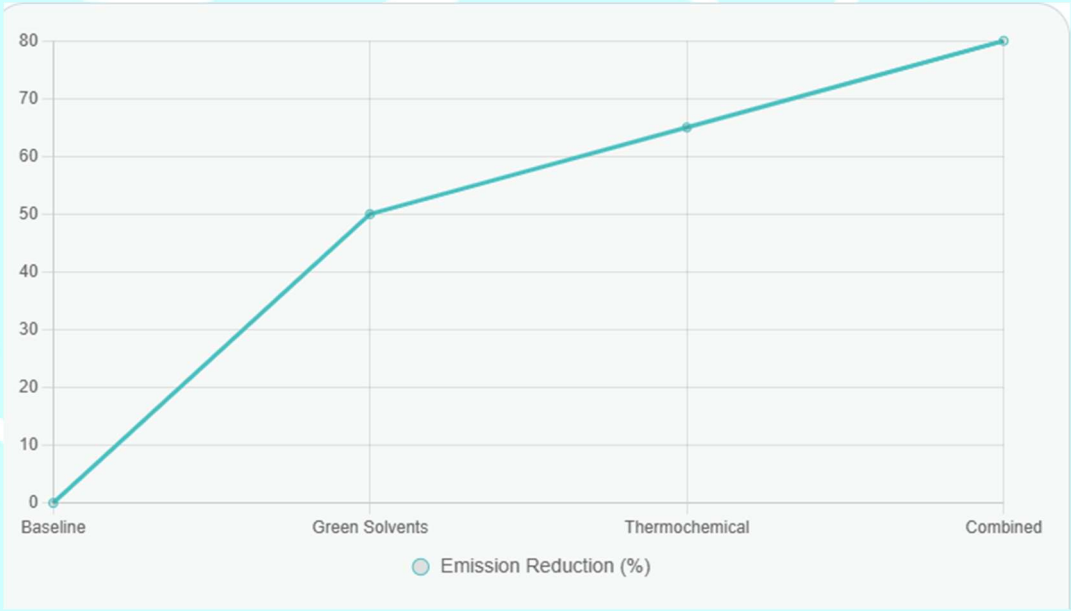


Figure 2: Lifecycle Emission Reduction Potential with Mitigation Strategies (Derived from Lab and Modeling Data, Refs. [10, 32]).

Discussion

Laboratory-derived toxicity thresholds and experimental recovery tests reveal that while gas condensate solvents pose acute risks (e.g., low IC50 for corals), green alternatives and recovery technologies offer viable reductions. Challenges like cost and scalability persist, but integrating these yields dual environmental and economic benefits. Future research should focus on expanded life cycle assessments (LCAs) and additional tropical species testing to quantify impacts comprehensively (6).

Conclusion

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Gas condensate-derived solvents significantly impact the environment, as evidenced by laboratory toxicity thresholds and emission data, but targeted mitigations—through alternatives, recovery, and regulations—can substantially reduce these effects. This aligns with global sustainability efforts, urging industries to adopt eco-friendly practices for long-term viability.

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