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TECHNOLOGICAL SOLUTIONS AND INNOVATIVE APPROACHES FOR THE TREATMENT OF EXHAUST GASES IN THE GAS PROCESSING INDUSTRY

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Abstract: This scientific work provides a comprehensive analysis of the composition of exhaust gases generated during gas processing, evaluates their environmental impact, and discusses the most effective technological solutions and innovative approaches for neutralizing hazardous components. The paper highlights pathways for reducing atmospheric pollution, enhancing environmental safety, and achieving economic efficiency through industrial waste recycling.

Keywords: gas processing, flue gases, atmospheric pollution, environmental safety, gas treatment technologies, adsorption processes, hydrogen sulfide (H_2S) utilization, carbon dioxide (CO_2) mitigation, emission monitoring and control, emission reduction.

Introduction

Today, the gas industry is developing rapidly as one of the key sectors of the global energy and chemical industries. Gas processing involves complex technological stages, including the removal of impurities from natural gas, its transportation and distribution to consumers, and the production of various chemical products. A significant consequence of these operations is the emission of harmful exhaust gases into the atmosphere, varying in both quantity and chemical composition. These emissions mainly contain hydrogen sulfide (H_2S), nitrogen oxides (NO_x), sulfur dioxide (SO_2), carbon monoxide (CO), volatile organic compounds (VOCs), methane (CH_4), and other hazardous substances that contribute significantly to air pollution, climate change, and adverse effects on human health.

Atmospheric pollution has become one of the most pressing global environmental challenges, leading to the implementation of increasingly stringent regulations by international environmental organizations and national governments. Consequently, reducing greenhouse gas emissions, improving industrial waste treatment efficiency, and ensuring environmental safety during industrial operations have become major priorities. Therefore, enhancing exhaust gas purification systems at gas processing facilities and introducing innovative treatment technologies are of great scientific and practical importance.

Conventional gas purification methods include absorption, adsorption, catalytic conversion, thermal oxidation, membrane separation, and biofiltration. Each of these technologies offers specific advantages and limitations, and their application depends largely on the physicochemical characteristics of the target pollutants. Moreover, the adoption of energy-efficient and cost-effective technologies contributes directly to the economic sustainability and competitiveness of industrial enterprises.

This article reviews modern methods for exhaust gas purification in the gas processing industry, examines approaches to improving environmental performance, and discusses the scientific basis for implementing advanced technological solutions.

Characteristics and Composition of Exhaust Gases

Waste gases generated during gas processing operations differ considerably in their chemical composition, physical state, particulate and aerosol content, toxicity, and thermal

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properties. Accurate classification and characterization of these emissions are essential for designing and selecting effective treatment systems.

The main characteristics of exhaust gases include:

- **Concentration of harmful components** – usually expressed in mg/m³ or parts per million (ppm);
- **Moisture content** – significantly affects purification and filtration efficiency;
- **Density and temperature** – influence gas flow behavior, volumetric rate, and reaction kinetics;
- **Corrosive and organoleptic properties** – for example, H_2S is highly toxic, has a strong unpleasant odor, and causes severe corrosion of metal equipment;
- **Combustibility and explosion hazards** – methane and VOCs present significant fire and explosion risks.

The principal pollutants found in gas processing emissions, together with their sources and environmental impacts, are summarized in the table below.

Substance	Primary Source	Environmental and Health Impact
Hydrogen Sulfide (H_2S)	Desulfurization and gas sweetening processes	Highly toxic gas; contributes to acidification of the environment and poses serious health risks.
Sulfur Dioxide (SO_2)	Oxidation and flaring of sulfur-containing gases	Causes acid rain, vegetation damage, and respiratory irritation.
Nitrogen Oxides (NO_x)	High-temperature combustion processes	Contributes to photochemical smog formation, respiratory diseases, and atmospheric pollution.
Carbon Monoxide (CO)	Incomplete combustion of hydrocarbons	Highly toxic; reduces the oxygen-carrying capacity of blood.
Carbon Dioxide (CO_2)	Fuel combustion and gas processing operations	Major greenhouse gas contributing to global climate change.
Volatile Organic Compounds (VOCs)	Evaporative emissions from petroleum and gas products	Precursors to ground-level ozone (O_3) formation and photochemical smog.
Dust and Aerosols	Mechanical processing operations and catalyst degradation	May cause respiratory disorders and adverse environmental impacts.

Innovative Approaches in Gas Purification

Beyond conventional absorption and adsorption loops, high-efficiency, energy-saving, and eco-friendly technologies are rapidly evolving to maximize contaminant retention and facilitate byproduct recycling.

1. Membrane Separation Systems

Membrane systems separate components based on molecular size and individual physicochemical affinities.

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- **Key Benefits:** Low energy footprint, compact physical design, high automation potential, and exceptional throughput for separating CO_2, H_2S, and VOC from gas streams.
- **Application:** Raw natural gas sweetening and carbon capture.

2. High-Energy Plasma Technology

Non-thermal and thermal plasma streams decompose complex hazardous gases into inert, non-toxic molecules.

- **Key Benefits:** Highly effective against resilient NO_x, VOCs, and dioxins; minimal physical footprint; eliminates the need for chemical reagents.
- **Limitation:** High initial capital expenditure and electrical energy consumption.

3. Industrial Biofiltration

Biological purification utilizes specialized microorganisms fixed onto a packing medium to degrade organic pollutants.

- **Key Benefits:** Environmentally benign, low operating expenditures, and excellent performance for low-concentration VOC and H_2S streams.
- **Limitation:** Restricted to low-concentration feed gases and requires strict climate control for microbial survival.

4. Carbon Capture, Utilization, and Storage (CCUS)

Since CO_2 is a primary greenhouse gas emission, two pathways are used to neutralize it:

- **CCS (Storage):** Injecting compressed carbon dioxide into deep geological formations or depleted reservoirs.
- **CCU (Utilization):** Transforming carbon waste into valuable commercial products, such as methanol, synthetic fuels, or polymers.

5. Smart Monitoring: AI and IoT Integration

Artificial Intelligence (AI) and Internet of Things (IoT) sensors enable real-time, continuous tracking of gas emissions.

- **Functions:** Facilitates instant automated adjustments if emission thresholds are breached, optimizes chemical dosing, and slashes resource consumption.

6. Nanostructured Catalysts and Heat Recovery

- **Nanocatalysis:** Maximizes active surface areas, significantly accelerating catalytic reaction kinetics for the deep conversion of NO_x and CO into benign N_2 and CO_2.
- **Waste Heat Recovery:** Captures thermal energy from exhaust streams to generate electricity or supplement secondary plant thermodynamic processes.

Conclusion

The purification of exhaust gases and the systematic reduction of industrial atmospheric emissions during gas processing are urgent priorities that span ecological, economic, and social domains. Transitioning toward advanced membrane systems, biological units, and AI-driven automated control frameworks allows industrial enterprises to ensure sustainable development, minimize public health risks, and preserve air quality. Ultimately, these green technological vectors lay a robust foundation for future academic research and industrial innovations.

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