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ENHANCEMENT OF WATER-GAS INJECTION TECHNOLOGY FOR OIL RESERVOIRS

The history of oil utilization by humanity dates back to ancient times, with industrial extraction beginning nearly two centuries ago. Despite advancements in renewable energy, oil remains a key global energy source for decades to come. Oil recovery factors typically range from 25% to 35% due to geological variations, leaving most fluids trapped in reservoirs. This poses a major challenge in the oil industry, prompting the development of enhanced oil recovery (EOR) methods. Waterflooding, discovered in the 19th century in the USA, is the most common due to its low cost, simplicity, and water availability. However, it fails to achieve high recovery rates, often resulting in increased water cut and additional preparation costs [1, 2].

Recent years have seen growing interest in water-gas injection (WGI) as an EOR technique that combines the benefits of waterflooding and gas injection while mitigating their drawbacks. WGI also addresses the disposal of associated petroleum gas. The research object is productive oil reservoirs suitable for WGI based on geological-physical and techno-economic criteria. The relevance lies in the inefficiency of conventional EOR methods, making WGI a promising solution [3, 4].

The study aims to analyze modern WGI technologies and their efficiency to select the most profitable implementation methods. Tasks include reviewing theoretical materials, examining WGI variants, studying domestic and international experiences, analyzing efficiency for optimal reservoir application, and identifying human health and environmental impacts [5].

WGI was first applied in 1957 in Alberta, Canada, with studies on over 70 fields worldwide showing an oil recovery increase of 5-10%. The process involves injecting water and gas alternately or simultaneously, maintaining and restoring reservoir pressure while enhancing recovery. This equalizes injectivity profiles and improves sweep efficiency both areally (by reducing mobility ratios) and vertically (via gas-water segregation), extracting oil from attic and bottom zones [6].

No unified WGI classification exists, but it can be divided by interaction with the displaced medium, injection method, and agent type.

By interaction: Miscible displacement occurs with full mutual solubility of oil and gas, eliminating interfacial tension through multi-contact component exchange. Gas enriches until a critical phase forms, achieving recovery coefficients of 0.95-0.98. Suitable for light oils in deep, low-permeability reservoirs with high pressure drops (30-40 MPa). Alternatively, liquefied hydrocarbon gases as solvents followed by dry gas. Immiscible displacement suits hydrophilic or mixed-wet collectors; water fills small pores, gas large ones, displacing oil. Relative permeability increases for non-wetting fluids. In hydrophobic rocks, early water breakthrough may occur. Gas and surfactants form micro-nuclei, enhancing filtration via a "gas bearing" effect, but insufficient surfactants lead to free gas phase and breakthrough.

By injection method: Alternating water and gas (WAG) involves gas injection for 2-3 months followed by water, effective for fractured reservoirs due to enhanced solubility and gravitational redistribution. Compressor-based uses high-pressure compressors (up to 10 per station); non-compressor utilizes high-pressure gas from caps or layers. Simultaneous injection uses gas-liquid mixtures (GLM) prepared surface-wise via booster plunger pumps or ejector systems, including pump-ejector and pump-compressor setups. Experiments on Canada's Joffre field showed simultaneous injection yielding higher incremental oil production and fewer operational issues than alternating, due to uniform gas distribution.

By agent type: Beyond standard water-gas, variants include hot steam for viscous oils, improving sweep and reducing viscosity via heat; foam with CO_2 and surfactants to control gas mobility, achieving up to 92% recovery by mitigating fingering and segregation; chemical additives like polymers or alkaline-surfactant-polymer for mobility control, increasing recovery by 7-14.3%; CO_2-WAG hybrids, where CO_2 slugs precede WAG, enhancing recovery but sometimes underperforming standard WAG.

Key geological-physical criteria for WGI: Reservoir depth and pressure minimum 1500-1800 m and 15-18 MPa for miscible; oil viscosity 5-10 mPa·s (up to 100 for miscible); temperature up to 100°C for light oils, 30-70°C injection for viscous; thickness 2-20 m for dipping reservoirs, unlimited for vertical; heterogeneity beneficial, smoothing via small slugs; permeability 0.005-0.1 μm^2 for gas, 0.02-0.8 for GLM; mineralogy avoiding CO_2-carbonate reactions; impermeable cap rock; presence of aquifers aiding segregation.

Techno-economic criteria: Prefer developed fields with existing waterflood infrastructure; upgrade for high-pressure pipelines and wellheads (up to 14 MPa, gas factors 1500-2000 m^3/m^3); gas-lift compatible wells; address short water-free periods, debit drops, hydrates, paraffins; intra-contour flooding with grid density as in waterflood; cheap associated gas sources; late-stage application viable despite lower economics than early.

Analysis of WGI technologies: Compressor alternating is capital-intensive with high costs for stations and pipelines, operational issues like uneven distribution. Non-compressor cheaper but limited. Simultaneous via ejectors efficient, low-cost, reliable, with high GLM stability. Pump-ejector systems optimize by placing ejectors downhole, reducing surface pressure needs. International experiences: USA's North Burbank showed chemical-enhanced WGI increasing recovery 14.3%; Dollarhide CO_2-WAG hybrid slightly underperformed standard. Canada's Joffre favored simultaneous. Russia's Samotlor and Ukraine's fields demonstrated ejector efficacy.

In conclusion, WGI analysis reveals its potential for enhancing oil recovery in diverse reservoirs. Proper classification and criteria selection ensure adaptability, with simultaneous injection and advanced agents like foam or chemicals offering superior efficiency. Implementation on developed fields with available gas maximizes techno-economic benefits, paving the way for sustainable oil production.

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