Temporary Relief of Damaged Casing Methane Emissions by Biotechnology

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Summary

Damaged well casings represent a persistent challenge in oil and gas operations, with surface casing vent flow (SCVF) and gas migration affecting approximately 10,000 wells in Alberta alone, emitting 65 million cubic meters of methane annually. While permanent casing repair through workovers or abandonment represents the ultimate solution, economic and logistical constraints often delay these interventions for years. This research presents a biotechnological approach for temporary methane emission mitigation using methanotrophic bacteria, providing regulatory compliance and environmental protection during the interim period before permanent repairs can be implemented.

The Methane Emission Microbial Conversion (MEMIC) technology utilizes naturally occurring methanotrophic bacteria to convert methane into less harmful carbon derivatives, including carbon dioxide, methanol, and biomass. Applied to wells with casing leaks, annulus communication, or packer integrity issues, this approach offers a cost-effective interim solution while permanent repair solutions are scheduled if possible. Field sampling, laboratory characterization, and mathematical modelling establish the technical foundation for deploying this biotechnology at damaged well sites.

Method and Workflow

The MEMIC workflow consists of four primary stages: (1) well characterization to determine leak location and methane flux rates, (2) microbial community assessment through field sampling of wellbore groundwater and soil around the wellheads, (3) laboratory testing to quantify indigenous methanotrophic activity and optimize nutrient formulations, and (4) field deployment with the chosen bioagent/methanotrophs and nutrient addition to the annulus, wellbore vicinity, or surface casing vent as appropriate.

Two implementation strategies are available depending on site conditions. Biostimulation activates indigenous methanotrophic communities already present in the near-wellbore environment through the addition of limiting nutrients (nitrogen, phosphorus, copper for methane monooxygenase enzyme activity) and oxygen derivatives if needed. This approach is particularly suitable for wells in environments with established methanotrophic populations, such as wetlands, coal-bearing formations, or areas with historical hydrocarbon seepage. Bioaugmentation introduces external methanotrophic consortia, either cultured from enriched indigenous bacteria or sourced from analogous environments, along with necessary nutrients. This approach provides more predictable performance but requires bioreactor cultivation and specialized deployment infrastructure.

Laboratory validation was conducted using samples from the Carbon Management Canada (CMC) field site representing various geological settings. Soil samples (4 g) and water samples (28 mL) were incubated in sealed serum bottles with 20% methane, 20% oxygen, and 2% carbon dioxide at 20°C. Gas chromatography tracked methane consumption over 126 days, while DNA sequencing identified active methanotrophic taxa. Samples showing significant activity (up to 90%

methane consumption within 28 days) confirmed the presence of viable indigenous methanotrophic communities capable of rapid activation.

Mathematical modelling using yield-based kinetic approaches established control parameters for field deployment. The models predict that efficient methanotrophic cultures (10^7 cells/mL) can achieve conversion rates of 2.24×10^{-8} to 10^{-7} liters CH_4 per liter of culture per hour (Ibatullin & Gieg, 2024).

Observations

Laboratory testing demonstrated that methanotrophic communities can be rapidly activated under appropriate conditions. Water samples from wells completed in coal formations showed 90% methane reduction within 28 days, while soil samples near observation wells achieved 85% reduction in the same timeframe. DNA analysis revealed that while many microorganisms were present in field samples, laboratory cultures showing methane consumption became enriched in methanotrophs and methylotrophs (Fig.1), particularly *Methylobacter*. *Methylobacter and Methylomicrobium* both use methane actively.

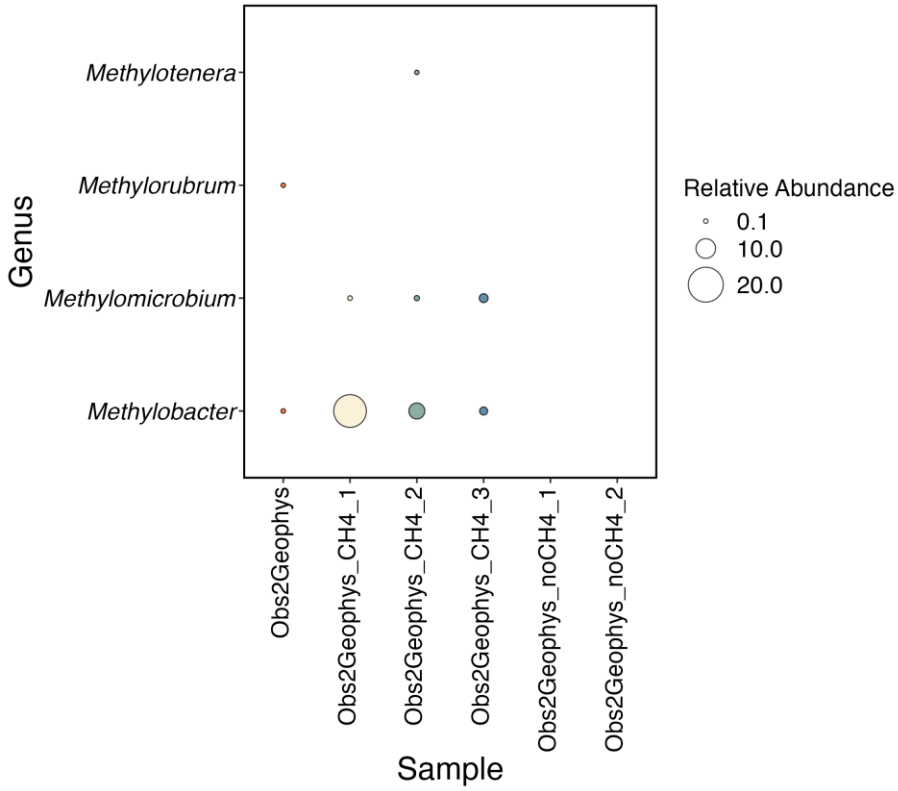


Fig.1 DNA analysis results for the soil samples from the vicinity of the Observation well

The technology builds on analogous field applications of microbial well treatment. Previous paraffin removal pilots in Tatarstan oil fields using hydrocarbon-oxidizing bacteria achieved 80-81% success rates across 28 wells over two years (Uvarov et al.1994). These precedents demonstrate that microbial agents can be successfully deployed in wellbore environments and maintain activity under field conditions. Economic analysis comparing hot oil treatment (conventional paraffin removal) versus microbial treatment shows significant cost advantages for biotechnology approaches.

The MEMIC technology extends this proven microbial approach to methane emission control, offering similar cost-effectiveness for leaks caused by damaged casing.

Mathematical modelling established that bacterial growth follows yield-based kinetics tied directly to methane consumption (Monod, 1949, Verhulst, 1838, Ivanov et al., 1978, Kolb et al., 2005). Growth rates of 0.02-0.05 hr^{-1} characterize the indigenous communities, with substrate consumption following exponential patterns ($R^2 > 0.91$). Results of the modelling of the microbial methane consumption demonstrate (Fig.2) the high potential conversion rate (Ibatullin & Gieg, 2024). Potentially, it's possible to process thousands of cubic meters of methane over 60-day periods with bacterial cultures ranging from 3 to 15 cubic meters per treated well.

There are more than 30.000 wells with Surface Casing Vent Flow (SCVF) and Gas Migration (GM) problems in Alberta only (Peleshok, 2023). For the estimated 10,000 problem wells in Alberta with cumulative cleanup costs projected to reach $1.1 billion by 2025 and individual well reclamation costs of $78,000, interim biotechnological mitigation can provide regulatory compliance at a fraction of immediate workover costs.

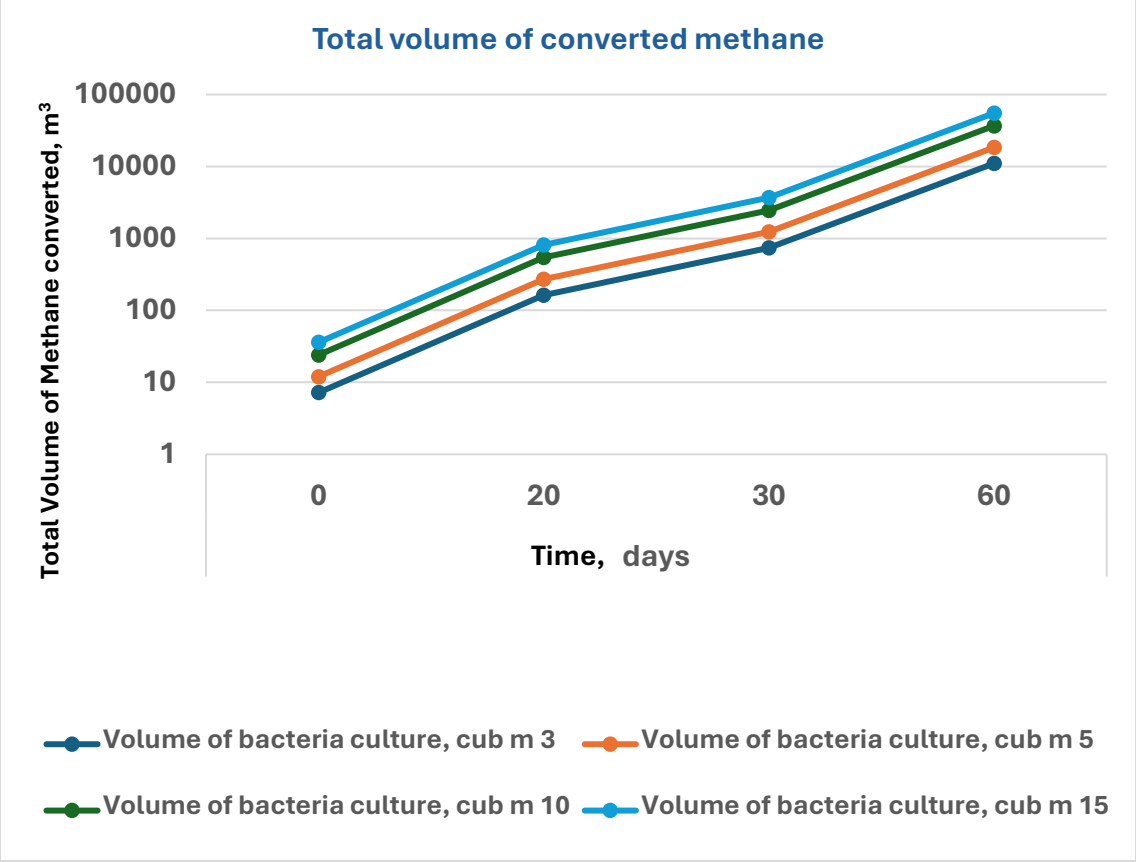


Fig.2 Dynamic of total converted methane volume (Ibatullin, Gieg, 2024)

The yield coefficient relating cell growth to methane consumed enables the prediction of treatment effectiveness based on leak rates. For SCVF rates that are uneconomic for the immediate repair, monthly treatments maintain active methanotrophic populations sufficient to convert substantial

portions of fugitive emissions to carbon dioxide, reducing the current environmental impact while permanent solutions are developed.

Novel

This research establishes a novel application category for microbial well treatment technology, extending proven hydrocarbon-oxidizing bacteria applications to methane emission control. The developing MEMIC technology addresses the growing regulatory and environmental imperative for emission reduction. The approach is particularly innovative in recognizing that temporary mitigation has substantial value in the context of deferred well maintenance backlogs.

The technology provides a practical solution to the temporal mismatch between regulatory requirements and capital availability for well repairs (Ibatullin et al., 2025). The immediate compliance through conventional methods is economically unfeasible for many operators. MEMIC technology enables progressive compliance by converting methane to carbon dioxide (reducing climate impact by a factor of 28-34) while wells await permanent repair or abandonment scheduling. Based on modelled substrate consumption dynamics, maintaining maximum conversion efficiency requires nutrient and oxygen agent replenishment at approximately monthly intervals, establishing the treatment schedule for continuous emission control.

The adaptability of the approach to different damage scenarios represents a key advantage. For annulus communication issues, bioagents can be circulated through the annular space. For casing leaks allowing gas migration to surface soils, soil-based biostimulation around the wellhead creates a biological barrier. This flexibility allows treatment protocols to be customized to specific well integrity issues without requiring immediate access to downhole equipment.

Integration with existing well integrity management protocols is straightforward. The technology does not preclude or complicate subsequent conventional repairs; rather, it provides emission control during the interim period. Monitoring protocols track both emission rates and microbial activity, providing data on treatment effectiveness while also characterizing leak dynamics that inform eventual repair strategies. The approach transforms damaged wells from uncontrolled emission sources to managed systems with quantified and progressively reduced environmental impact.

Acknowledgements

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