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Alberta Upstream Petroleum
Research Fund

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Public Summary of Quantification of Methane Emissions from Stationary Engines

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This report presents the findings of an independent, unbiased study designed to evaluate the performance of engines as they relate to methane slip under specific real-world operational conditions. The primary objective of this study was to assess how stationary engines function within the unique parameters and constraints of the field environment, rather than to provide a comprehensive evaluation or endorsement of any technology itself.

The results and conclusions reflect observations and data collected during the study period and are specific to the conditions and context of the operations in which the technology was deployed. Variations in site conditions, operational practices, or technology configurations may yield different outcomes.
This report is not intended to be used as a definitive judgment of the overall effectiveness, reliability, or value of any technology, but rather as a resource to inform stakeholders about its performance in the observed context. The report contains best practices that may optimize engine performance. Stakeholders are encouraged to consider this information alongside other data and insights when making decisions regarding the technology's use.

Any opinions, findings, and conclusions or recommendations expressed in this publication are those of the author(s) and do not necessarily reflect the views of the [Parties], Clean Resource Innovation Network (CRIN) or its members.

Foreword

This document is a non-technical summary of the significant findings presented in the 'Quantification of Methane Emissions in Stationary Engine Exhaust and Best Management Practices for Mitigation (2024) ', known hereafter as 'The Study'. The Study, prepared by Accurata Inc. and funded by the industry fund, Alberta Upstream Petroleum Research Fund (AUPRF), Canadian Emissions Reduction Innovation Network (CanERIC), and Clean Resource Innovation Network (CRIN), has the potential to make a substantial impact on our environment by significantly reducing methane emissions. The Petroleum Technology Alliance Canada (PTAC) managed the project.

This document provides a summary of The Study's findings to supplement the technical reader's understanding of the findings presented in The Study and to facilitate the project's understanding for non-technical audiences. For technical details and a full analysis of the methodology, analytical approach, and findings, please refer to The Study, available to PTAC members or AUPRF funders at ptac.org.

Introduction

Methane slip refers to unburned methane that escapes from stationary natural gas engines. These emissions contribute to greenhouse gas (GHG) emissions, with Alberta's stationary engines estimated to release approximately 4.9 million metric tonnes of carbon dioxide equivalent (CO_2e) annually. Current methane slip estimates are based on outdated United States studies, making it essential to conduct field studies for more accurate data from a Canadian context.

The Study, which summarizes and analyzes the findings from extensive testing on 100 engines across 116 tests, provides practical insights. It not only explores factors affecting methane emissions but also suggests best practices for reducing emissions. Furthermore, it draws comparisons between different engine models, fuel compositions, and combustion styles, offering a clear picture of industry trends and challenges.

1 Background Information

2.1 What Are Large Stationary Engines Used for in Alberta?

In Alberta, large stationary natural gas engines are integral to the energy infrastructure. They play a crucial role in oil and gas production, power generation, and industrial applications. These engines drive compressors that transport natural gas through pipelines, generate electricity for remote industrial operations, and support large-scale mechanical processes. Their reliability and ability to use locally available fuel make them vital to Alberta's energy infrastructure.

2.2 Major Components of Large Stationary Engines

Major engine components include:

- Crankcase: houses the engine's moving parts and manages oil circulation.
- Air Manifold: directs air into the combustion chamber.
- The Exhaust System carries away combustion gases, sometimes using a catalyst to reduce emissions.
- Turbocharger: uses exhaust gas to improve engine efficiency by increasing intake air pressure and
- Cooling System: maintains optimal engine temperature to ensure complete combustion.

2.3 What is Methane Slip and Why Does it Occur?

Methane slip occurs when some natural gas fuel remains unburned and escapes through the engine's exhaust. This can happen because of several factors, including:

- Incomplete combustion occurs when some methane does not react fully with oxygen (O_2).
- Crevice trapping occurs when methane gets trapped in small engine crevices and is released unburned.
- Misfire or spark failure can lead to most or all of the fuel flowing to the exhaust.
- Air-fuel mixture imbalances, which can lead to inefficient combustion.
- Cooling near chamber walls, which can cause some methane to cool before burning; and
- Crankcase blowby, where unburned methane can leak from the combustion chamber into the crankcase and escape through crankcase emissions if not properly managed.

2.4 What is the Air-Fuel Ratio and What Does it Mean for an Engine to be Rich- or Lean-Burn?

The air-fuel ratio (AFR) represents the proportion of air to fuel in the combustion process. Applying the optimal AFR is essential for efficient combustion. When the fuel mixture has excess fuel, it is described as a rich mixture and can lead to incomplete combustion and, therefore, higher methane slip. When the fuel mixture has excess air, it is described as a lean mixture that can result in lower exhaust temperatures and lead to methane slip due to cooling. The optimal AFR ensures complete combustion, minimizing emissions while maximizing efficiency.

Engines can be run rich or lean to regulate the production of nitrogen oxides (NOx) and sulfur oxides (SOx), which are harmful pollutants. Engines that utilize rich mixtures are called rich-burn. They produce higher NOx emissions because the excess fuel results in higher combustion temperatures. Rich-burn engines often require additional NOx reduction strategies, such as exhaust gas recirculation or selective catalyst reductions. Rich-burn engines also increase carbon monoxide (CO) and unburned hydrocarbons, including methane.

Engines that utilize lean mixtures are called lean burn. They generate less CO and unburned hydrocarbons but may create difficulty maintaining a stable combustion process. The balance between rich and lean operations depends on regulatory limits, operational requirements, and emission control strategies.

2.5 What Is a Catalyst and How Does It Work?

A catalyst is a device in the exhaust system that facilitates chemical reactions to reduce harmful emissions. In rich-burn engines, catalysts convert NOx, CO, and unburned hydrocarbons into less harmful substances like nitrogen, water, and carbon dioxide (CO2). However, they are less effective in reducing methane slip.

2.6 Variations in Fuel Quality

Natural gas composition can vary depending on its source, affecting combustion efficiency. Methane content can vary in natural gas, where higher methane levels improve combustion efficiency. Impurities, such as heavier hydrocarbons or contaminants, can affect engine performance. Excess moisture can reduce combustion efficiency and damage components.

2.7 What Other Factors Can Affect Combustion?

Many other factors can affect combustion in stationary natural gas engines, which may lead to methane slip. These can include:

- Valve timing is the precise control of when intake and exhaust valves open and close, which affects engine efficiency and emissions.
- Air-fuel mixing, as properly mixing fuel before combustion supports even burning and may reduce unburned methane; and
- Factors like temperature, pressure, and humidity can also influence combustion efficiency and methane slip. For example, lower temperatures can result in cooling, while higher temperatures improve combustion efficiency.

2 Key Findings

3.1 Understanding Methane Slip

Methane slip occurs for many reasons, which include incomplete combustion, crevice trapping, and air-fuel imbalances. The Study identifies four primary engine types, each with distinct emission patterns:

1) **Rich-burn engines without catalysts:** These engines normally operate at a near-stoichiometric air-fuel ratio, without post-combustion emissions control technology.
2) **Rich-burn engines with catalysts:** These engines normally operate at a near-stoichiometric air-fuel ratio, with post-combustion emissions control technology. The non-selective catalyst reduction process is designed to primarily reduce NOx emissions.
3) **Open-chamber lean-burn engines:** These engines normally operate at a lean air-fuel ratio, use excess air to promote complete combustion, and reduce combustion temperature (which results in NOx emissions reduction).
4) **Pre-chambered lean-burn engines:** These engines normally operate at a lean to ultra-lean air-fuel ratio, use excess air to promote complete combustion, and reduce combustion temperature (which results in NOx emissions reduction). These engines operate using a pre-combustion turbulent jet combustion chamber which helps enhance the combustion stability under ultra-lean conditions.

The Study also examines the role of valve timing, air-fuel mixing, and operating temperature in influencing methane slip. For example, engines with high valve overlap tend to exhibit greater methane slip due to unburned fuel escaping into the exhaust stream.

3.2 Factors Affecting Methane Emissions

Several operational and design factors influence methane slip. Engine tuning and control systems are both factors affecting methane slip. Adaptive controls can optimize combustion conditions and minimize unburned fuel. Managing temperature is important, as higher exhaust temperatures generally correlate with lower methane slip due to more complete combustion. Fuel quality and composition variations affect combustion efficiency, including methane concentration and energy content.

Maintaining an appropriate AFR supports more efficient combustion. Both engine age and maintenance history are important factors; older engines with wear and tear exhibit higher methane slip. Engine crankcase ventilation systems that redirect unburned gases back into the combustion process help reduce emissions. The Study found that engines with better air-fuel mixing, and advanced control systems had significantly lower methane emissions than older, mechanically controlled models.

3.3 Best Practices for Reducing Methane Slip

Operators can reduce methane slip through a combination of technology upgrades and operational improvements. Regular maintenance, including periodic checks and overhauls, help maintain peak performance and reduce emissions.

Monitoring and optimization are important strategies for detecting and preventing methane slip. Monitoring fuel consumption helps detect inefficiencies and potential methane leaks. Load optimization supports engines running at optimal load to prevent excessive fuel consumption.

Upgrading engine controls and design may support reduced methane emissions. Adaptive controls adjust fuel delivery in real time to optimize combustion on an ongoing basis. Implementing an ingestive crankcase ventilation system prevents unburned methane from escaping into the atmosphere.

Installing an ingestive crankcase ventilation system and optimizing fuel use offer the most cost-effective solutions, often paying for themselves within months through fuel savings.

To reduce methane slip, upgrading to new engines that utilize modern designs that integrate features that inherently reduce methane emissions is an option; however, it may not be cost-effective.

4 Study Highlights

4.1 Field Testing Program

The Study collected methane emissions data from various engines under actual operating conditions. The result showed a wide emission variation, primarily due to differences in engine condition, fuel quality, and air-fuel ratios. Key observations from the field-testing program include:

- Methane emissions ranged from near zero to over 1,000 ppmvd @ 15% O_2*.
- Lower NO_x emissions are correlated with higher methane emissions in non-catalyst engines.
- Lean-burn engines saved more fuel than catalyst-equipped rich-burn engines.
- Engines that underwent regular maintenance showed a 30-50% reduction in methane slip compared to poorly maintained units; and
- The role of excess O_2 was found to be more complex than previously thought, with some engines displaying higher emissions at specific air-fuel ratios.

  * ppmvd is a unit used to measure gas emissions in parts per million by volume and dry. Dry means that the sample has had all moisture removed before measurement. 15% O_2 means that the gas concentration in an exhaust gas stream is regulated as if it were diluted by enough air to reach an O_2 concentration of 15%.

4.2 Crankcase Emissions

A significant portion of methane emissions originate from the crankcase, where unburned gases escape past piston rings. The Study found that:

- Crankcase emissions account for 20-60% of total methane slip.
- Installing an ingestive crankcase ventilation system can nearly eliminate these emissions.
- Several manufacturers offer retrofit kits for crankcase emission control and
- Engine power output correlates strongly with crankcase methane emissions, suggesting that larger engines contribute disproportionately to total methane slip.

4.3 Emission Factors and Estimates

Emission factors were developed using field data to estimate total methane slip from Canada's stationary engine fleet. These estimates have an uncertainty of approximately 40% due to assumptions in engine models and operating conditions. The Study estimated total methane slip emissions of 182,500 tonnes per year in Canada, with 127,800 tonnes per year in Alberta. Of that, estimated crankcase methane emissions are 73,700 tonnes per year in Canada, with 53,100 tonnes per year in Alberta. The study emphasizes that improving data collection and measurement accuracy is essential to refine these estimates and support regulatory frameworks.

5 Technology and Cost Considerations

The Study evaluated various mitigation technologies, including:

- **Ingestive Crankcase Ventilation Systems:** These systems cost from $20,000 to $80,000 per installation but provide long-term savings by reducing methane emissions and improving fuel efficiency.
- **Fuel Gas Metering:** Helps track consumption changes that indicate maintenance needs.
- **Adaptive Engine Controls:** Adjust parameters in real-time to optimize combustion and
- **Catalytic Converters:** Reduce NOx but may not significantly impact methane slip.

A key recommendation is to prioritize low-cost, high-impact solutions such as crankcase ventilation systems and fuel optimization before investing in expensive retrofits.

6 Future Research Needs

Several areas require further investigation to refine methane emissions reduction strategies, including:

- Understanding the relationship between air manifold pressure and methane slip.
- Exploring why methane slip does not always correlate with engine wear and overhaul frequency.
- Examining the impact of engine oil ash content on emissions.
- Assessing the long-term performance degradation of catalysts; and
- Refining estimates of crankcase methane emissions to improve emission reduction strategies.

7 Conclusion

The Study underscores the need for improved monitoring and targeted interventions to reduce methane slip from stationary engines. By implementing best practices, operators can significantly cut emissions while improving engine efficiency and reducing fuel costs. Moving forward, additional research and regulatory refinements will help establish more accurate emission factors and industry-wide mitigation strategies.