Reducing methane emissions from natural gas reciprocating engines: The silent contributor to global climate change

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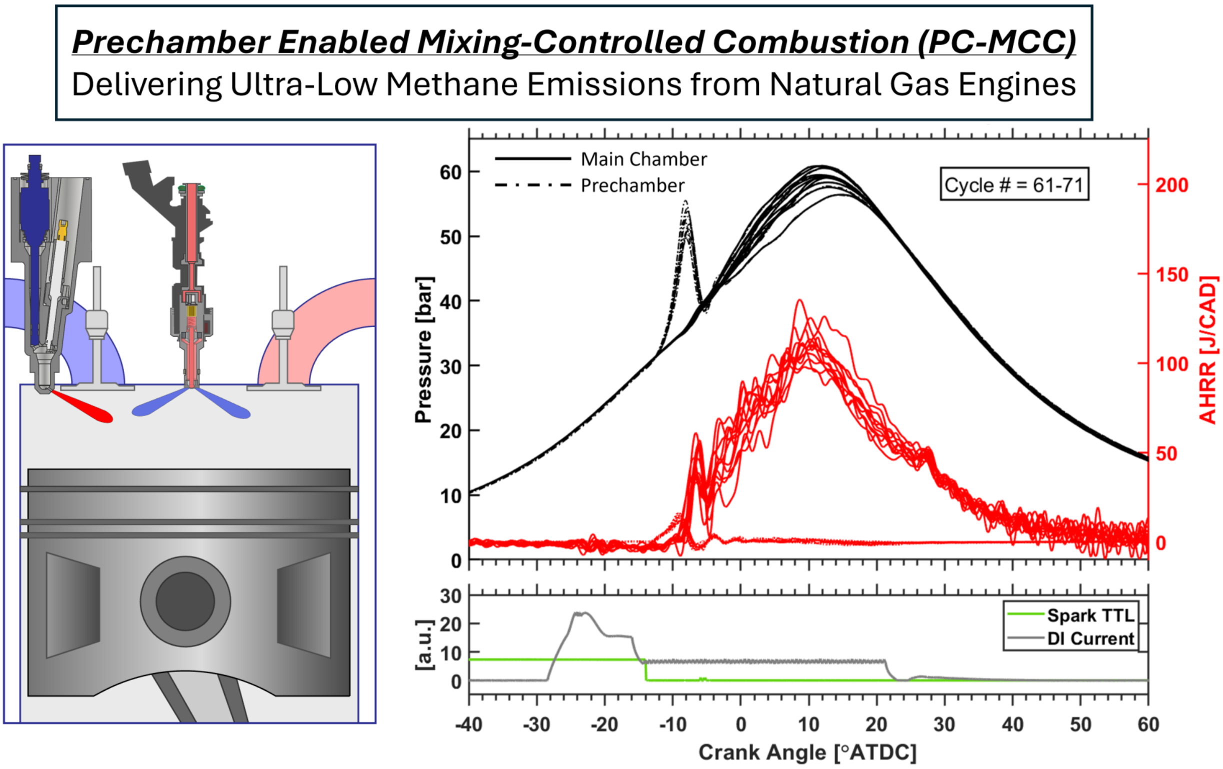

While natural gas is a cleaner-burning alternative to coal and diesel, its use comes with a significant downside: methane emissions. Adam Dempsey from Marquette University highlights prechamber-enabled mixing-controlled combustion as a promising technology for reducing methane slip from natural gas engines

Natural gas usage around the globe has increased by ~20% over the last decade, and it now accounts for ~25% of the world's energy supply. Natural gas is an attractive fuel for electricity generation, heating, and even transportation – because it is abundant, lower cost, cleaner burning, and lower carbon intensity compared to petroleum-derived fuels. Natural gas emits ~25% and ~50% less CO2 per unit energy compared to diesel fuel and coal, respectively. Thus, increased natural gas usage in all energy sectors appears to be a positive trend for reducing carbon emissions and battling against climate change.

However, there is a looming downside to natural gas usage – methane emissions. Methane (CH4), the primary constituent that makes up natural gas, in the atmosphere has a global warming potential of ~28 times higher than CO2 over a 100-year period. [1]

With the increase in natural gas usage and the various sources of methane emissions associated with it, the atmosphere's methane concentration has risen by ~20% in the last 50 years. There are many anthropogenic sources of methane emissions, such as landfills and ruminant livestock, but natural gas systems – drilling, gas gathering, gas transmission, and end usage – are the greatest anthropogenic sources of methane. Methane emissions are often overlooked as a contributor to global climate change. Still, with natural gas usage on the rise, methane is rapidly becoming a major issue that must be solved.

There are methane sources that can be addressed without significant need for technological innovation, such as ending routine venting and flaring, capping abandoned wells, fixing pipeline leaks, capturing and using landfill gas, and improving manure handling procedures. One of the major sources of methane emissions that is not straightforward to resolve is unburned natural gas from combustors and engines, which is referred to as methane slip.

Mitigating methane slip

Natural gas reciprocating engines are historically used in stationary power generation – for power levels from several kilowatts up to ~20 megawatts [(2)] – and pipeline natural gas compression. Recently, marine shipping, [(3)] railroad, and on-road commercial vehicles have seen an increase in natural gas reciprocating engines used for propulsion as well. Alternatives to these large natural gas engines, such as electric motors, batteries, and fuel cells, are extremely cost-prohibitive and are very far from delivering the energy density required for these extremely high-power applications. Thus, society needs a pragmatic solution to methane slip from natural gas engines to allow these engines to stay in service while combating global climate change.

Nearly ubiquitously, reciprocating natural gas engines use a premixed charge of fuel and air, which is ignited by a small injection of diesel fuel or a spark plug. In these engines, the methane slip is ~2 to 5% of the total fuel supply, stemming from unburned crevice and quench regions, blowby to the crankcase, and short circuiting of fuel from the intake directly to the exhaust – all of which are a result of the premixing of the fuel and air in the engines intake system. [(4)] The most pragmatic way to reduce or eliminate methane slip is by avoiding these sources altogether, which requires fundamentally changing the in-cylinder combustion process from premixed to a non-premixed. This is done by directly injecting natural gas into the engine cylinder near top dead center, right when combustion is about to begin. This eliminates the short-circuiting and unburned crevice and quench layers. In this type of combustion system, the fuel must auto-ignite readily, and unfortunately, natural gas is very resistant to autoignition. To make this system a reality, an ignition assistance device is needed for the direct-injected natural gas.

Prechamber enabled mixing-controlled combustion Prechamber Enabled Mixing-Controlled Combustion (PC-MCC) is an engine technology that uses an actively fueled prechamber and a high-pressure direct injector, both fueled with natural gas. The prechamber is fueled with a small amount of natural gas, and the mixture is ignited by a spark plug, which generates burning jet flames that penetrate the main combustion chamber, rapidly igniting the direct injected natural gas at the right time. This results in a predominantly non-premixed combustion process that yields ultra-low methane emissions by avoiding the classic unburned fuel sources that plague today's natural gas engines. In engine testing, PC-MCC has been shown to reduce methane emissions by ~90%, relative to today's spark ignited natural gas engines [(5)]. This was achieved at equal NOx emissions.

The PC-MCC engine technology is attractive because it achieves a non-premixed combustion process with nearly any fuel, regardless of the fuel's propensity for autoignition. PC-MCC engines are fuel agnostic and can operate on ethanol, methanol, natural gas, hydrogen, or ammonia. Because PC-MCC engines do not use any premixed fuel, their torque and power output are never limited by abnormal combustion, such as knock and pre-ignition, which is the case for spark ignition engines. Thus, PC-MCC can use high compression ratio, deliver the thermal efficiency of a diesel engine, while being fuel agnostic and reducing greenhouse gas emissions. The energy landscape is constantly evolving, as society searches for more sustainable and clean energy sources. For commercial transportation, power generation, marine, rail, and natural gas compression systems, the internal combustion engine is here to stay, and we need technological innovations and investment to reduce its carbon footprint.

References

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