ON-BOARD REFORMATION DEVICE FOR METHANE ABATEMENT FROM GAS ENGINES

A cost-effective way to reduce methane emissions from stationary natural gas engines

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ABSTRACT

BACKGROUND

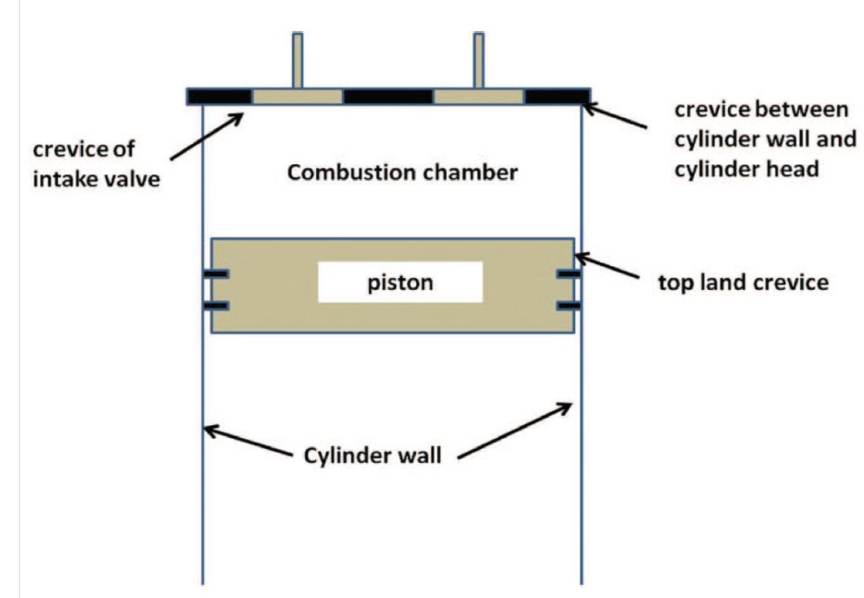
- With over 20,000 engines in upstream and downstream O&G sectors, methane slip in stationary engines can be substantially large.
- This project is to design and develop a compact natural gas reformation device that effectively harnesses exhaust heat and increases the hydrogen concentration in the fuel. This can promote in-cylinder methane oxidation.

OBJECTIVES

- Reduce methane emissions in the tail pipe > 50%. (Overall conversion of methane in the engine > 99.5%)
- Improve engine thermal efficiency > 5% points while complying with US-EPA mandated NO_x emissions (< 1.34 g/kW-hr) for stationary engines.
- payback period < 2 years (mostly fuel savings).
- Should overcome catalyst poisoning by sulfur and carbon and should have a lifetime > 10 years of continuous field operation (i.e., > 95% availability).

MOTIVATION

- In reciprocating engines, low temperatures in crevice volumes result in incomplete methane oxidation.



METHODS/ GOALS

Steam Methane Reforming (SMR)

$CH_4 + H_2O$ (+heat) $\leftrightarrow CO + 3\ H_2$

Water-Gas Shift (WGS)

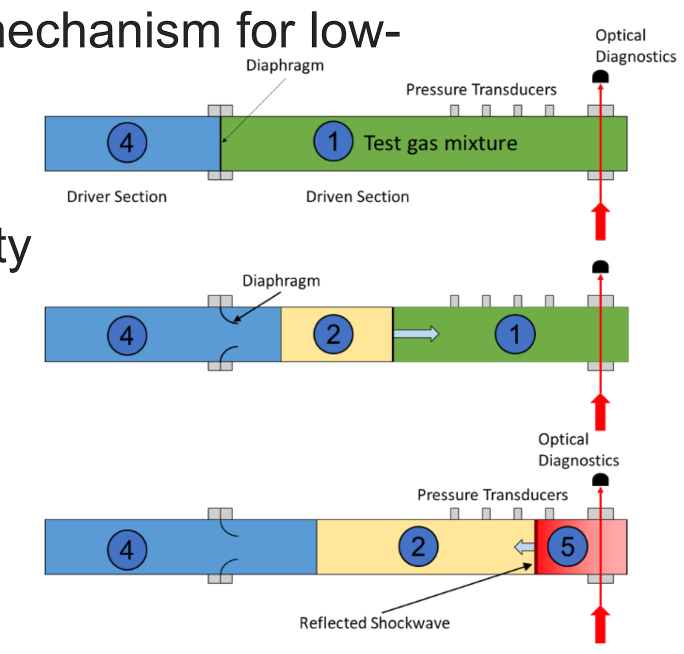
$CO + H_2O \leftrightarrow CO_2 + H_2$ (+ δ heat)

- On-board generation of hydrogen; $[H_2]$ ~ 30% vol. in fuel.
- Reformation temperature ~ 450^{o}C while avoiding carbon poisoning.
- Harness exhaust heat to promote system efficiency.

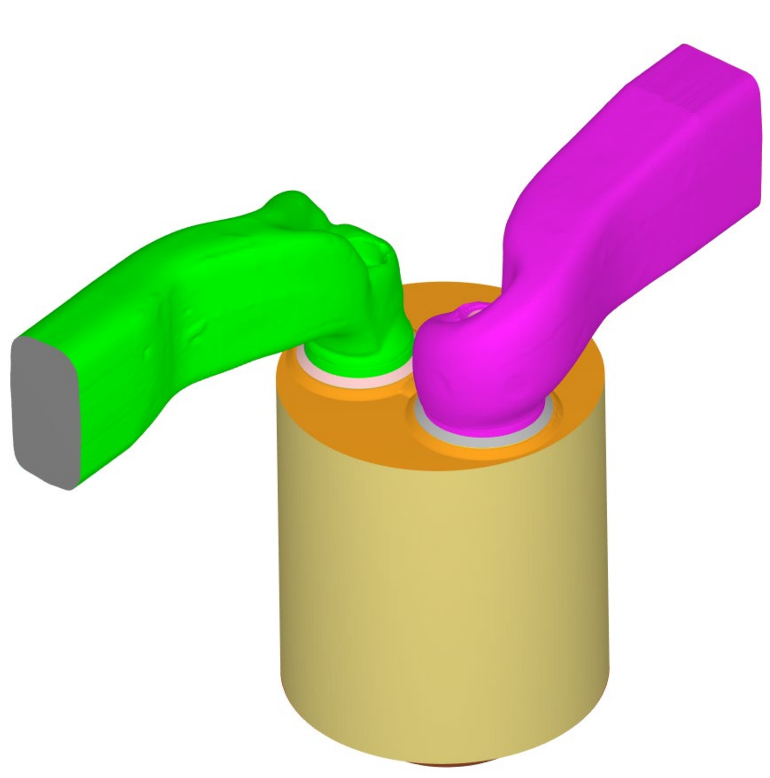
DESIGN STUDIES

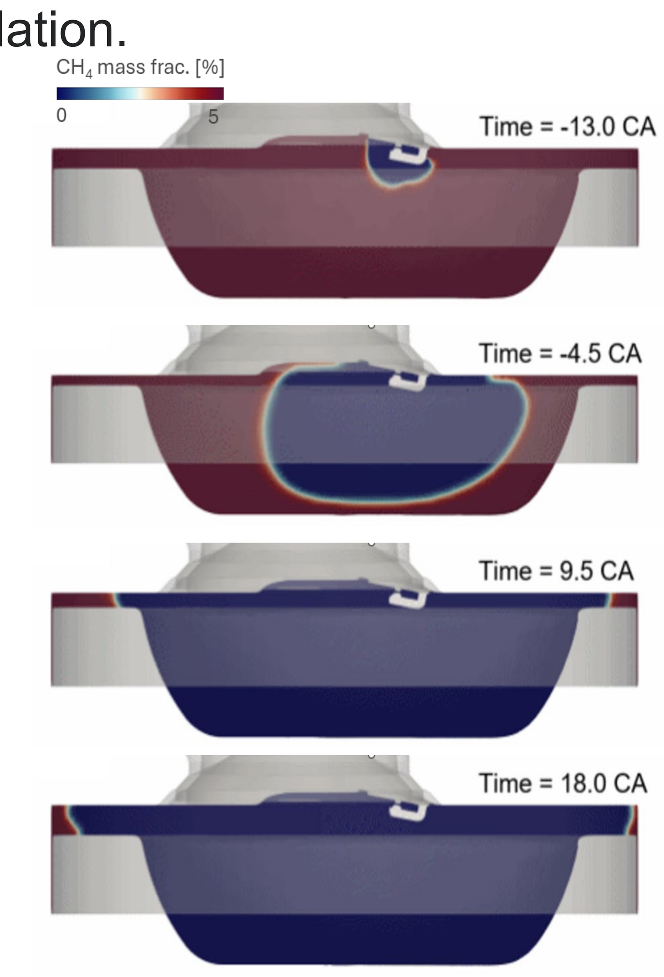
Low-temperature Methane Oxidation Mechanism

- Shock tube studies to tune methane kinetic mechanism for low-temperature (~400^{o}C) oxidation
- Shock tube tests in UCF's HyPERSTAR facility
- Start with ARAMCO 3.0 mechanism
- Reduced kinetic model development using ANSYS CHEMKIN PRO



- 1-D modeling and CFD simulations to identify the most effective fuel composition for in-cylinder methane oxidation.





SYSTEM DEVELOPMENT

Reformer Development

- compact heat exchanger and plate reformer paired with a high efficiency low-temperature (~450^{o}C) catalyst.
- Custom catalyst coatings on plates.
- reforming tests for stability, conversion of methane a

VARIABLES

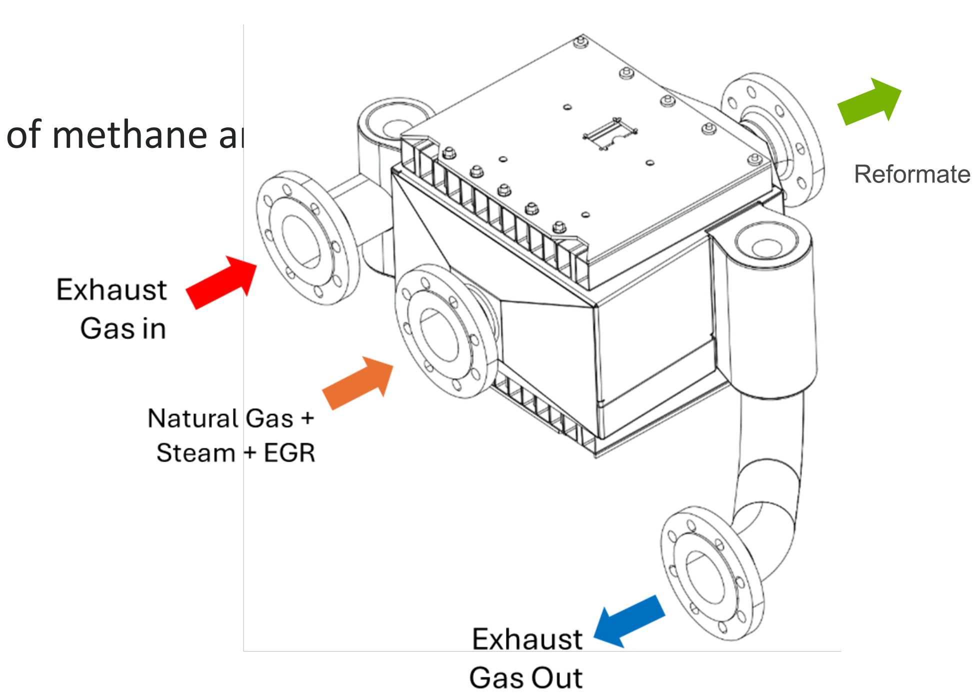
λ =1/ϕ = Excess air ratio

α - fraction of NG to reformer

β - fraction of exhaust to reformer

OBJECTIVE

$[H_2]$ = 30% vol.



- Test platform is a research engine in Argonne's test cells.

Engine Specifications	Single-Cylinder,4-Stroke, SI, Naturally aspirated
Bore (mm)	130
Stroke (mm)	140
Comp. Ratio	11:1
Displacement (L)	1.857
Power (kW/hp)	33/45
Speed (rpm)	1800
Spark Ignition System	CDI (Altronic, Inc.)
Lube oil and Coolant Conditioning	Separate unit
Fueling	PWM Injection in intake manifold

CONCLUSIONS

- On-board hydrogen generation to promote in-cylinder oxidation of methane is the most reliable and cost-effective way to reduce methane emissions from stationary natural gas engines.
- An optimal system design is a trade-off between H_2 concentration and calorific content of the fuel stream.
- This strategy also offers the potential to improve engine efficiency by recycling waste exhaust heat. Brake thermal efficiency above 50% could be anticipated. This in turn will reduce CO_2 emissions from the engine.

NEXT STEPS

- Complete 1-D modeling to optimize on the operable α, β, λ and the amount of steam addition.
- Design and develop a catalyzed heat exchanger that efficiently harnesses engine waste heat while enabling fuel reformation.
- Benchmarking reformer performance using simulated fuel compositions in the laboratory.
- Final demonstration of reformer equipped engine in an engine test cell.

REFERENCES

- Estimates of Methane Emissions by Segment in the United States | US EPA
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