An Evolutionary Approach to Very High Efficiency Methanol Engines for Maritime Applications

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First Phase

Spark Ignition engine with similar efficiency to diesel engine:

- Uses established engine technology
- Very low emissions
  - Option for operation as compression ignition engine that operates entirely on diesel
Second Phase

Use “Reformer based” exhaust heat recovery

In spark ignition engine:

- Increase efficiency by up to 25%
- Enhance economic attractiveness
- Reduce greenhouse emissions
- Option for operation entirely on diesel fuel as compression ignition engine
Spark ignition (SI) Engine

• Ignition of premixed fuel and air by flame propagation from an electrical discharge (Otto cycle)

• Can operate with stoichiometric fuel/air ratio
  - Lower emissions than diesel engine
  - More effective energy recovery (higher exhaust temp)

• Ignition can alternatively be provided by use of a small amount of diesel fuel (pilot compression ignition)
Diesel-Like High Efficiency In SI Engine

• High octane of methanol prevents knock (unwanted detonation) that limits performance of spark ignition engine

• Allows high compression ratio and high level of turbocharging / engine downsizing (40% smaller size than diesel with same efficiency and torque)

• Diesel –like high efficiency demonstrated in engine tests using port fuel injection (EPA Ann Arbor)

• Additional performance and efficiency improvement using octane enhancement from direct injection or open-valve port fuel injection (MIT)
Emissions

• Spark ignition engine uses low cost and highly effective three way catalyst (TWC) to reduce pollution to very low levels.

• Diesel engine without particulate and NOx exhaust after -treatment produces very high pollutant levels.

• Clean diesel engine uses complex and expensive exhaust gas treatment system (urea SCR + particulate filter) to substantially reduce pollution (but it is still not as low as spark ignition engine).
Spark Ignition Methanol Engine With Option For Diesel Operation

- Relatively simple modification of diesel engine
- Add port fuel injector for methanol
- Add spark plug (or use diesel pilot ignition)
- Use fuel from methanol tank or diesel tank
- Option for operating entirely on diesel fuel
Super-efficient Spark Ignition Methanol Engines

Efficiency gain relative to standard gasoline engine

- Removal of knock limit (higher octane)
- High compression ratio
- Turbocharging and downsizing
- Exhaust heat recovery

55% - Diesel engine
50%
45%
40%
35%
30%
25%
20%
15%
10%
MIT Optimized Waste Heat Recovery

1. Spark ignition engine
   (stoichiometric fuel/air ratio provides higher exhaust temperature and better heat transfer than diesel)

2. Reform methanol into hydrogen-rich gas that has more chemical energy and is then combusted in engine

3. Open Rankine cycle: further increase heat recovery

4. Metallic foam heat exchanger
Waste Heat Recovery by Reforming Methanol

Low temperature catalytic reforming

\[ \text{CH}_3\text{OH} \rightarrow 2\text{H}_2 + \text{CO} \] (syngas)

Endothermic decomposition

Syngas has more energy than methanol
Methanol Injection at High Load

- Methanol Injection can be used to add knock resistance to syngas
- Methanol use minimized in order to reform as much methanol as possible
- Increased knock resistance from vaporization cooling
  - Direct Injection
  - “Open-valve” port fuel injection (removes need for adding additional penetration in modified engine)
Open Rankine Cycle

• Rankine cycle uses heat to convert pressurized liquid into hot gas that does mechanical work

• In Open Rankine cycle gas is introduced into engine rather than being condensed into liquid

• Gas has energy from both chemical conversion of methanol to syn gas and increased heat energy

• Hot gas is used to do mechanical work and also provides fuel with increased chemical energy to engine
Methanol Open Rankine Cycle With Engine Energy Recovery

- Heat Exchanger system transfers exhaust heat to methanol and syngas
- Produces syngas with higher chemical energy and higher temperature
- Syn gas is introduced into engine so as to do mechanical work on piston and is then combusted
- “Open” Rankine cycle: working fluid is introduced into engine rather than being recycled.
Heat Recovery By Mechanical Work in Engine

- Inject hot H2-rich gas during compression stroke prior to sparking
- Injection through valve that is separate from air in take valve
Methanol Open Rankine Cycle With Turbine Energy Recovery
Metallic Foam Heat Exchanger

- New compact heat exchanger increases reformer effectiveness
- Use of metallic foams improves exhaust heat transfer to gas
  - great thermal contact with gas (lots of surface area)
- However, because of very high porosity, foams have poor thermal conductivity
- This drawback is removed by combining foam with fins that have high thermal conductivity
porous metal foams
“Foam on Fins” Heat exchanger For Exhaust Heat Recovery

- Need efficient, compact heat exchanger design for vehicular applications
- Foam metals are very attractive
  - High surface heat transfer coefficient,
  - However, have low thermal conductivity
  - Solution: Foam on fins
Cryogenic heat exchanger
current lead for superconducting applications
Potential Reformer Exhaust Energy Recovery with Other Engines

- Diesel pilot ignited Otto cycle engine with lean operation
- Diesel- methanol dual-fuel Compression Ignition Engine
- Premixed Compression Ignition Engines
- Tradeoffs need to be assessed
Potential Use of Open Methanol Rankine Cycle in Gas Turbine

- Methanol under pressure is reformed into syngas which has more chemical energy than methanol

- Syngas also has elevated temperature that is provided by heat exchange with turbine coolant and exhaust gas

- Syngas powers first turbine and is then combusted in burner to power second turbine

- Potential efficiency increase of 25 %
Summary

- Evolutionary use of spark ignition type methanol engine can provide
  - Near term use of well established engine technology with very low emissions and with option for operation entirely on diesel fuel
  - Longer term use of highly effective exhaust heat recovery

- Methanol offers potential for very effective waste heat recovery
  - Recover heat from engine exhaust (major) and coolant (minor)
  - Potential engine efficiency ~ 55-60%
    (considerably exceeds diesel efficiency and can rival fuel cell)
  - Could significantly increase attractiveness of using methanol for ship propulsion