An Otto Rankine Combined Cycle for High Efficiency Distributed Power Generation

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ARES
Advanced Natural Gas Reciprocating Engine Systems

Funding:
Project Description

Distributed energy systems require clean, high efficiency power generation to gain acceptance in an industry dominated by large centralized facilities.

Project Team

- Caterpillar Energy and Sustainability
- Caterpillar Advanced Materials
- Caterpillar Electronics
- Caterpillar Diversified Power Products
- Caterpillar Electric Power Division
- Consultants
- Universities

CAT® + Cummins + Dresser Waukesha = 90% U.S. Gas Engines
Project Description (continued)

Objective:
By 2010, create a natural gas powered reciprocating engine system with the following attributes:
- 50% thermal efficiency
- 0.1 gram/bhp-hr NO\textsubscript{X} or less
- 10% reduction in life cycle costs
- No loss of reliability or availability

Approach:
Phased Introduction

I  44% Efficiency
   0.50 g/bhp-hr NO\textsubscript{X}

II 47% Efficiency
   0.1 g/bhp-hr NO\textsubscript{X}

III 50% Efficiency
   0.1 g/bhp-hr NO\textsubscript{X}

ARES Program Overview

Task Description

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G3520 – 44.0% Efficiency
0.5 g/bhp-hr NO\textsubscript{x}
Production engine that meets ARES Phase I efficiency goals
3.83 GW of Caterpillar ARES Product Installed or in Process

North America
749 MW
DER / Power Security / Power Quality

Central and South America
187 MW
Prime Power

Europe / Africa / Mid-East
1892 MW
CHP / Prime Power

Asia / Australia
1005 MW
CHP / Prime Power
ARES Summary

- ARES program is a shining example of Public / Private partnership in technical innovation and product introduction

- ARES technology provides a flexible platform for
  - Distributed Generation
  - Combined Heat & Power Applications
  - Renewable / Opportunity fuels utilization
ORCC – Otto Rankine Combined Cycle

Otto

Rankine

\[
\begin{align*}
\text{log(Pressure)} & \quad \text{log(Volume)} \\
\text{Combustion} & \quad \text{Expansion} \\
\text{Compression} & \quad \text{Intake} \\
\text{Exhaust} & \quad \text{Blow-Down}
\end{align*}
\]

\[
\begin{align*}
\text{Heat to Evaporator from Exhaust} & \quad \text{Turbine} \\
\text{Pump} & \quad \text{Condenser}
\end{align*}
\]
Exhaust Energy Recovery - Motivation

Energy (~25% of fuel LHV) in hot (>500°C) exhaust is usually not recovered for useful purposes.

Recovering exhaust energy will improve efficiency and thus reduce brake specific NOₓ and CO₂ emissions.
Rankine Cycle

- **Pump**: Moves fluid from the condenser to the evaporator.
- **Evaporator**: Converts fluid to vapor at a lower pressure.
- **Turbine**: Utilizes the energy from the vapor to produce work.
- **Condenser**: Returns the fluid to its liquid state at a lower pressure.

**Diagram Details**:
- **Temperature-Enthalpy Diagram**:
  - **Heat to Evaporator from Exhaust**
  - **Condenser**
  - **Turbine**

**Process Steps**:
1. **Condenser** → \( Q \) → **Evaporator** + \( W \) → **Turbine** → **Condenser** → \( Q \)
Components for Parallel Recuperated Cycle:

- **Pump**
- **Preheater** (A)
- **Evaporator** (B)
- **Superheater** (C)
- **Recuperator** (D)
- **Condenser** (E)
- **Turbine**

**Flow Diagram:**

1. **Air** enters from the bottom left and flows through the pump (2).
2. **P_flow** connects to the preheater (A).
3. **Evaporator** (B) connected to the recuperator (D) via 3P and 4.
4. **Superheater** (C) connected to the recuperator (D) via 5.
5. **Turbine** connected to the recuperator (D) via 6.
6. **G3520C Engine Exhaust** flows into the recuperator (D).
7. **Condenser** (E) connected to the recuperator (D) via 8.
8. **To Exhaust Stack** (33).

**Flow Type:**
- Green line = Working Fluid R245fa
- Red line = Engine Exhaust
ORC System Layout

- Exhaust Valve
- Heat Exchangers
- Turbine Generator
- Recuperator
- Condenser
- Control Panel
- ORC System
- Caterpillar G3520C

PDCOE
Energy & Sustainability
Phase-II Demonstration
Bearing Failure
Turbine End Bearing

Non-Turbine End Bearing

Rigid Shaft Between

Preload Path

Lube Drain Channels

Preload Spring (90 lb)

3 lube jets (120 deg apart at r = 1.215) per side (6 total)

3 lube jets (120 deg apart at r = 1.215)

.47 gpm, Fluid Velocity = 20 m/s
Questions?
Turbine and Pump wheels
**Turbine Generator**

- **Turbine, Generator, and Feed Pump on an Integral Shaft.**
  - 18,000 RPM Design Speed
  - Total Weight: 1500 lb

- **Radial Turbine**
  - 10.8” OD, 850 ft/s Tip Speed
  - 365 psia @ 425 F Inlet Condition.

- **Generator**
  - 4 Pole PM
  - 375 KW, 600 VAC, 410 Amps, 600 Hz
  - Water Cooled

- **Feed Pump**
  - 320 psid
  - 67 gpm

- **Angular contact bearings**
  - 900,000 DN @ 18 krpm
  - “Jet” lubricated with R245fa.