Particle Separator for Improved Flameless Pressurized Oxy-Combustion (FPO)

DOE National Energy Technology Laboratory

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Principal Investigator:

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Project Team: SwRI, ITEA, EPRI, GE Global Research

Overview

- Team Overview
- Objectives
- Background on the Technology
- Design Selection
- Detailed Design
- Testing

Project Team

Principal Investigator

Southwest Research Institute

Testing Partner

Itea, S.p.A.

Development and Analysis Partners

Electric Power Research Institute

GE Global Research

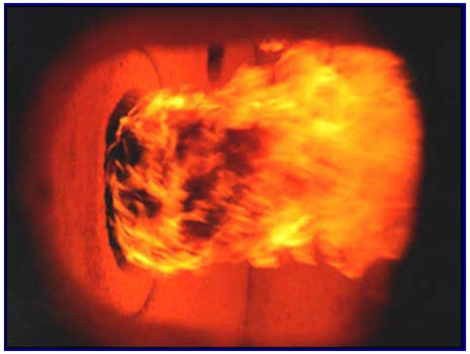
What are the objectives of the proposed project?

- Select a design capable of separating FPO particles
- Perform a detailed design and integration with test facility
- Achieve particle removal with a low pressure loss at a high temperature
- Evaluate material properties of particles and impact on separator surfaces
- Assess economic potential of the separator technology

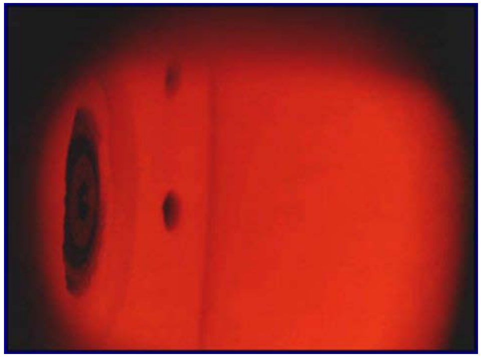
Background on FPO

- Pressurized atmosphere of water and CO_2 under "volume expanded combustion"
  - FPO combustion is more locally controllable with more uniform temperatures
  - Pressurized firing with oxy-combustion also improves cycle efficiency
- Chemical balance in combustion is near stoichiometric
  - Achieved through CO_2 recycle, water, and oxygen balance control
- Almost zero carbon content in incombustible products
  - Traditional: flying and falling ash particles
    - Must be filtered and collected from gas stream
  - FPO: slag with near-zero carbon content
    - Drains out the bottom of the combustor
    - Particulate still exists in exhaust but at reduced quantities and sizes

Traditional Combustion with Flame Front

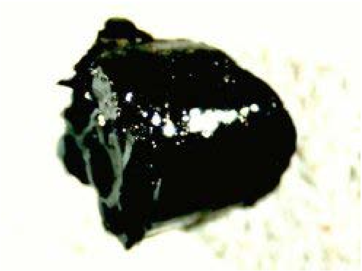


Flameless Pressurized Combustion



Traditional Combustor Products: Particulate

FPO Combustor Products: Near-zero carbon, neutral slag



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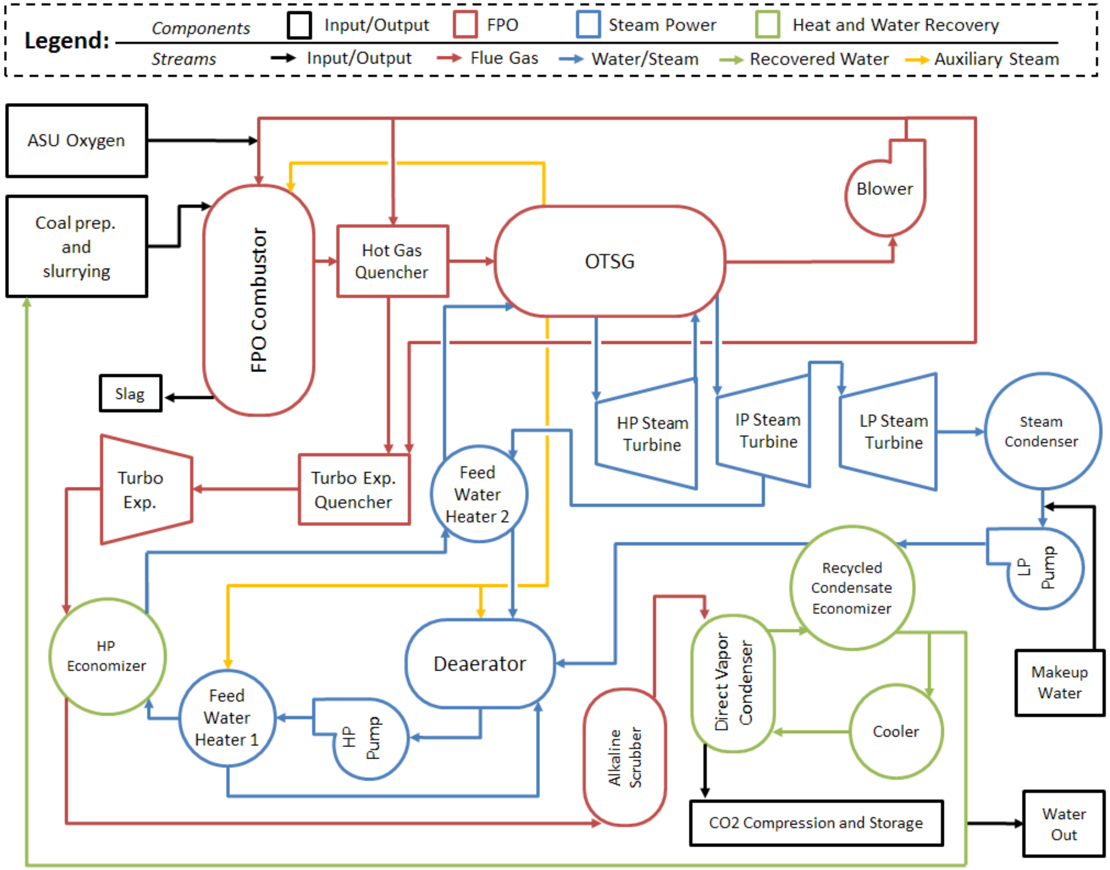
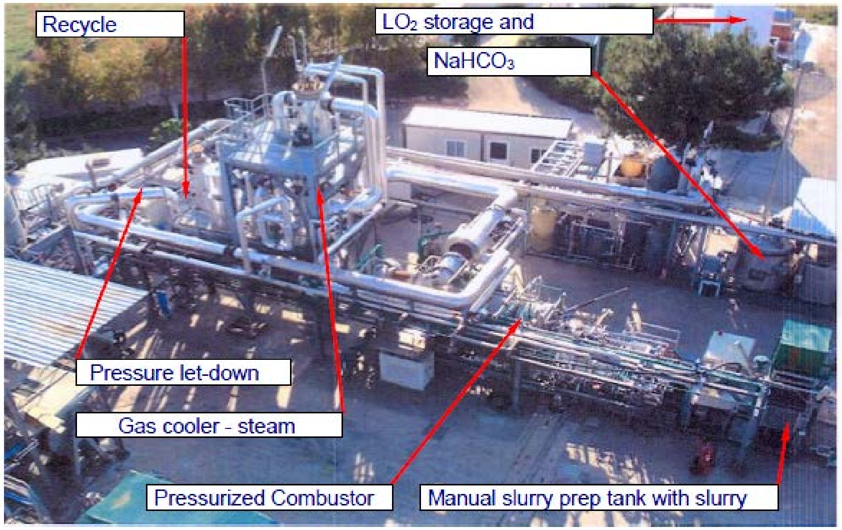
What is the FPO Cycle?

- Slurry of milled coal and water combusted under pressure
- Hot combustor gas is quenched through mixing
- Enters OTSG
- Portion of flow leaves the process with energy before the OTSG and is expanded
- A large percentage of combustion products are recycled
  - Some recycled flow used for quenching
  - The remainder of recycled flow is mixed with pressurized oxygen and injected into the combustor



What is the State of the Technology?

- 5 MWth plant in Italy
  - Capable of 4 bar (58 psi) pressure
  - Over 18,000 hours of testing experience
  - Technology proven with high and low rank coals
  - Test location for the particle separator
- Techno-Economic assessment at the commercial scale
  - In process under another DOE FPO development process
  - Continued assessment will be developed by the same team at EPRI and SwRI



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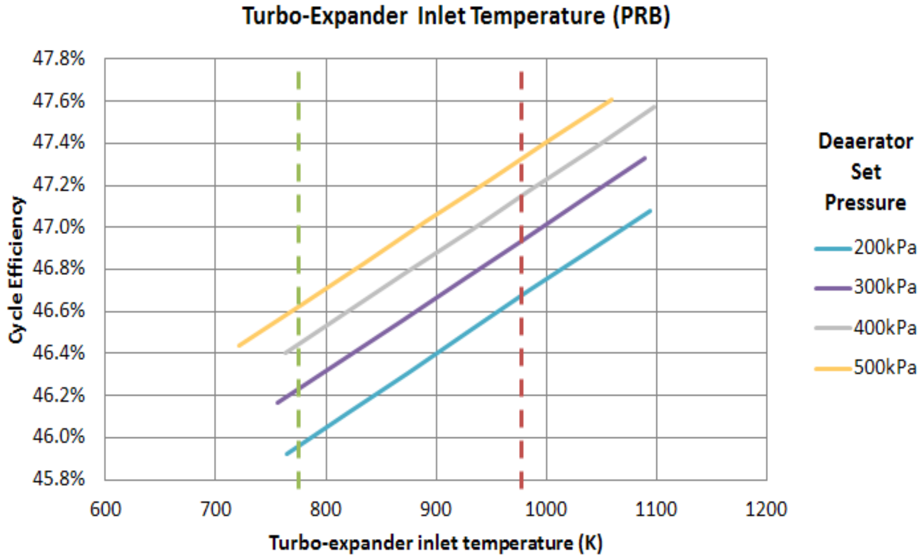
Why Particle Separation?

- Demonstrated improved performance of pressurized cycle with recovered energy
- Applicable to technologies other than FPO
- Limits of the turbo-expander inlet temperature could be improved to the red line
  - Requires demonstrated ability to withstand high temperatures
- Goal to minimize pressure drop in order to maximized pressure ratio of expander



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Technical Approach: Selection of Design

- Initial evaluation of available particle separator technologies
  - Select based on pressure loss, removal performance, and high temperature performance
- Assess ability to remove mass from flue gas stream with preliminary numerical analysis
- Develop an economic case for a particle separator
  - Based on initial performance estimates and final results

Selection of Design: Particle Removal Criteria

PROCESS	ALLOWABLE PARTICULATE LOADING		DETERMINING FACTOR	CONTROL DEVICE USED OR PROPOSED
	S.I. UNITS	ENGLISH UNITS		
Open cycle coal-fired gas turbine, Pressurized fluidized bed coal combustion, and Combined cycle low-BTU coal gasification	2.3 mg/m³ >2 μm 43 mg/MJ <2 μm	0.001 gr/SCF >2 μm 0.1 lb/10⁶BTU* <2 μm	Turbine wear Emissions	Cyclones, followed by filters; hot electrostatic precipitators, or granular bed filters
High BTU coal gasification	4.6 mg/m³	0.002 gr/SCF	Pipeline quality	Cyclones followed by high efficiency scrubbers
FCC catalyst regenerator	0.001 gram of particulate per gram of coke burnt off	0.001 lb particulate per lb coke burnt off	Emissions	Electrostatic precipitators, baghouses, scrubbers, granular bed filters
Metallurgical furnaces (in general) Steel electric arc furnaces	50.4 mg/m³ 11.9 mg/m³	0.022 gr/SCF 0.0052 gr/SCF	Emissions Emissions	Electrostatic precipitators, high efficiency scrubbers, and baghouses

*Current new source performance standards are 0.1 lb/10⁶BTU, however a stricter standard of 0.05 lb/10⁶BTU has been proposed.

- Table from Parker and Seymour with typical separation schemes
- Flow curvature higher in turbomachinery, so potential for erosion is high
- Coal fired turbomachinery has a low loading criteria
  - Typically cyclones and filters
  - Includes electrostatic separation technology

Potential Candidate Designs

- May require some combination of designs
- Inertia Separator
  - Flow curvature in an axial direction
  - Inlets to engines in dusty environments
- Conventional Cyclone
  - Flow curvature of a vortex
- Electrocyclone
  - Electrostatic attraction of charged particulate in a vortex
- Acoustic Agglomerator
  - Sound pressure to remove fine particles
- Ceramic Barrier Filter
  - Hard porous ceramic
- Ceramic Baghouse
  - Woven ceramic

Selection of Design: Evaluation Matrix

Category / Item	Weighting	Inertia Particle Separator	Conventional Cyclone Separator	Electrocyclone	Acoustic Agglomerator	Ceramic Barrier Filter	Ceramic Bag House
Physical Attributes							
Are there any special permits required to operate the equipment?							
Are there any corrosion concerns with the equipment/system?							
Are special materials/manufacturing processes required?							
Is the equipment/system sensitive to different types of coal flue ash?							
What is the equipment/system size?							
What is the construction impact on the equipment/system?							
Does the equipment/system need to be used in combination with other systems?							
Does the equipment require additional specialized equipment?							
Environmental and Permitting							
What waste products are generated?							
Is there any Haz/Mat issues?							
How loud is the equipment?							
What are the emissions from the equipment/system?							

Selection of Design: Evaluation Matrix

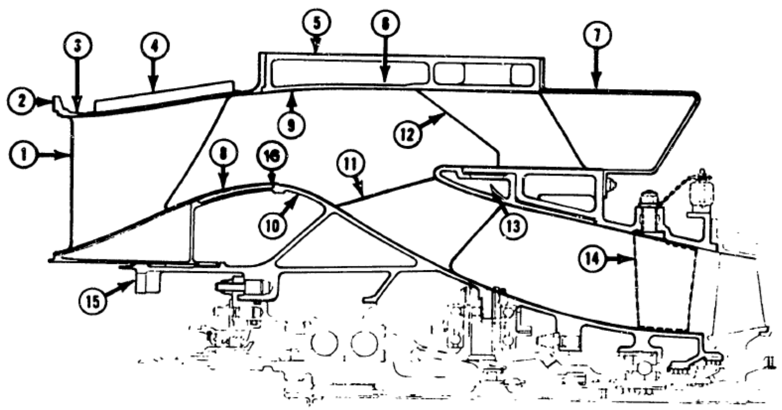
Category / Item	Weighting	Inertia Particle Separator	Conventional Cyclone Separator	Electrocyclone	Acoustic Agglomerator	Ceramic Barrier Filter	Ceramic Bag House
Operations							
How does changes in temp/pressure/gas flow affect the efficiency?							
Does the system require pneumatics/hydraulics?							
Does the system require power?							
Does the system remove large particles?							
Can the system/equipment be located outside without cover or protection?							
Does the system remove small particles (less than 10 micrometers)?							
What are the system maintenance requirements?							
What is the system pressure drop?							
Is the equipment/system capable of 24/7 operation?							
Is the system tolerant to high temperatures (500-700 degC)?							
What are the system monitoring requirements?							

Selection of Design: Evaluation Matrix

Category / Item	Weighting	Inertia Particle Separator	Conventional Cyclone Separator	Electrocyclone	Acoustic Agglomerator	Ceramic Barrier Filter	Ceramic Bag House
Business and Financing							
Is the technology readiness high for the proposed equipment?							
Does the commercially available equipment have a long lead time?							
What is the system/equipment material cost?							
Does operation of the equipment/system require manufacturer support for operation?							
What is the system/equipment operating cost?							
Do any of the participating organizations have experience with the equipment/system?							

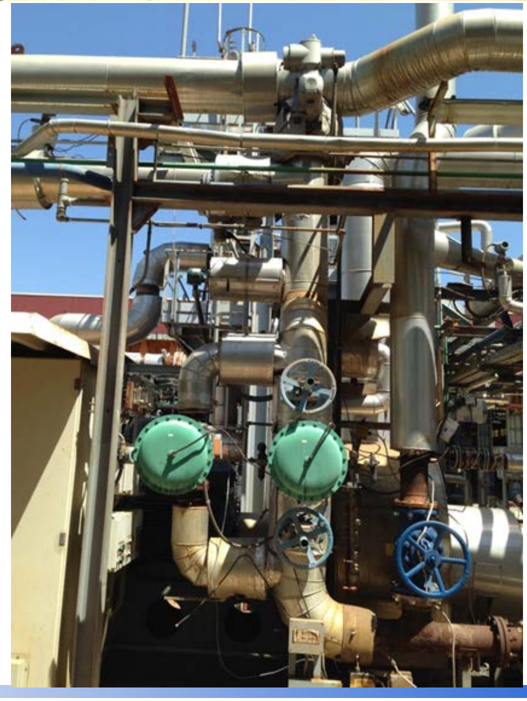
Technical Approach: Detailed Design

- Based on chosen selection, begin analytical evaluation
  - Flow analysis showing minimized pressure loss
  - 3D modeling with mechanical analysis of strength
- Develop detailed design
  - Analysis of pressure boundary and seals
  - Detailed drawings for fabrication
- Develop integration plan with existing 5MWth test facility



Technical Approach: Testing

- Testing at 5MWth facility
  - 3.45 kg/m^3 density gas
  - With 0.13-0.27 m^3/s at the boiler exit
- Monitoring of Combustion Products
  - Particle speed and velocity: Electrical Low Pressure Impactor (ELPI)
  - Gas: Continuous process analyzers
    - Non-Dispersive Infrared Sensors
    - Hydrogen Flame Ionization Detector for Total Organic Content
  - Separated and Unseparated particles collected with batch filtration
    - SEM and x-ray diffraction for particle microstructure
    - Dynamic Light Scattering and SEM for particle size analysis
  - Analysis of impact and wear on separator surfaces



Thank You

- References:
  - R. Parker and C. Seymour, "High-Temperature and High-Pressure Particulate Control Requirements, "U.S. Environmental Protection Agency: Office of Research and Development, Washington D.C., 1977.