TDA RESEARCH

Direct combustion of fine coal from coal waste

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Project Overview

SBIR Phase I (April, 2018 – January, 2019), $150,000

Phase II (May, 2019 – May, 2021), $1,000,000

Team

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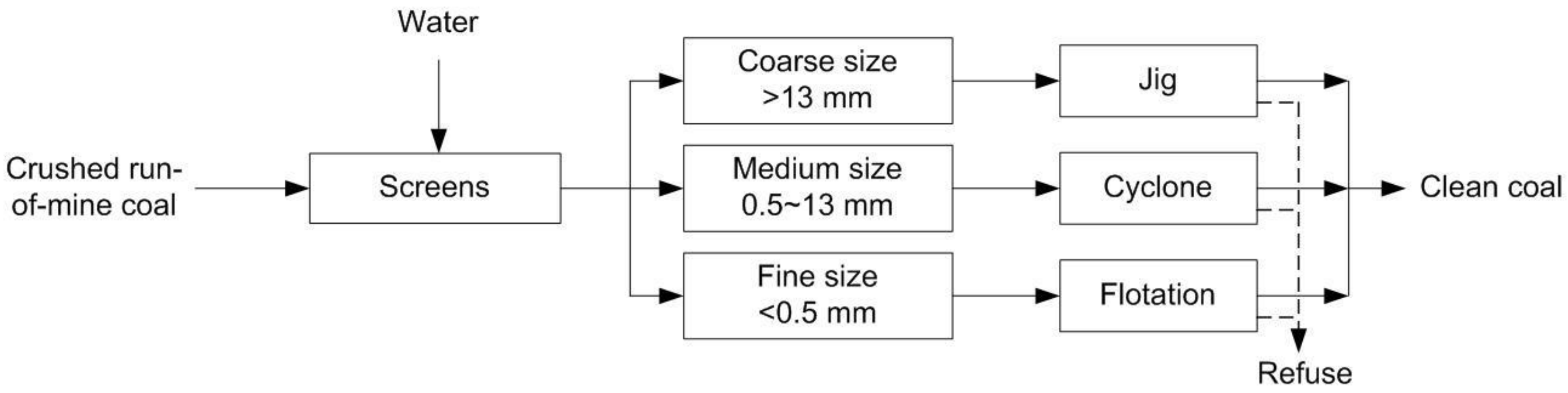
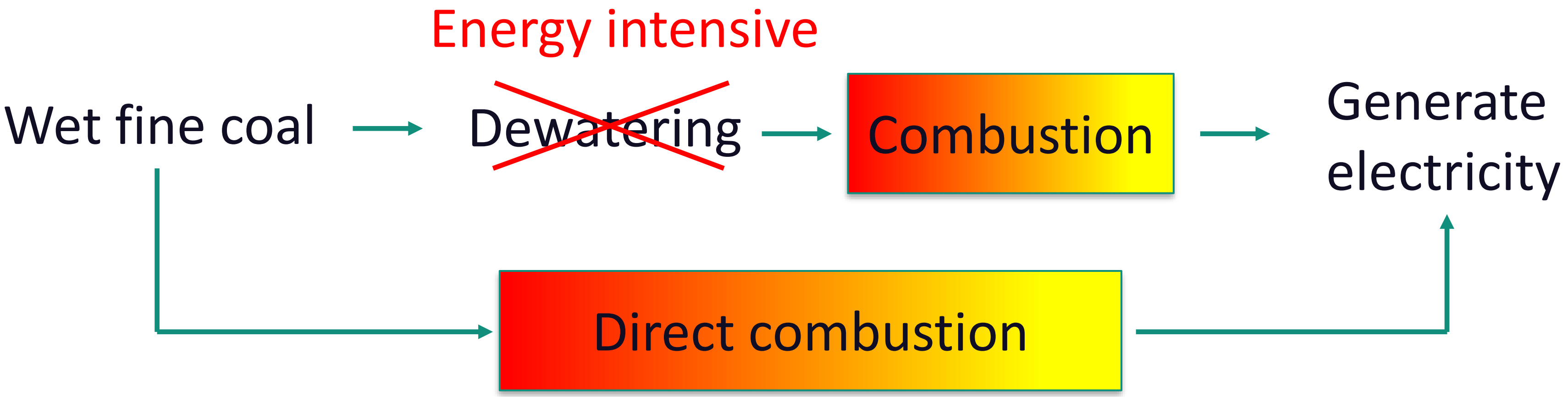
4 Billion tons of Fine Coal in the USA

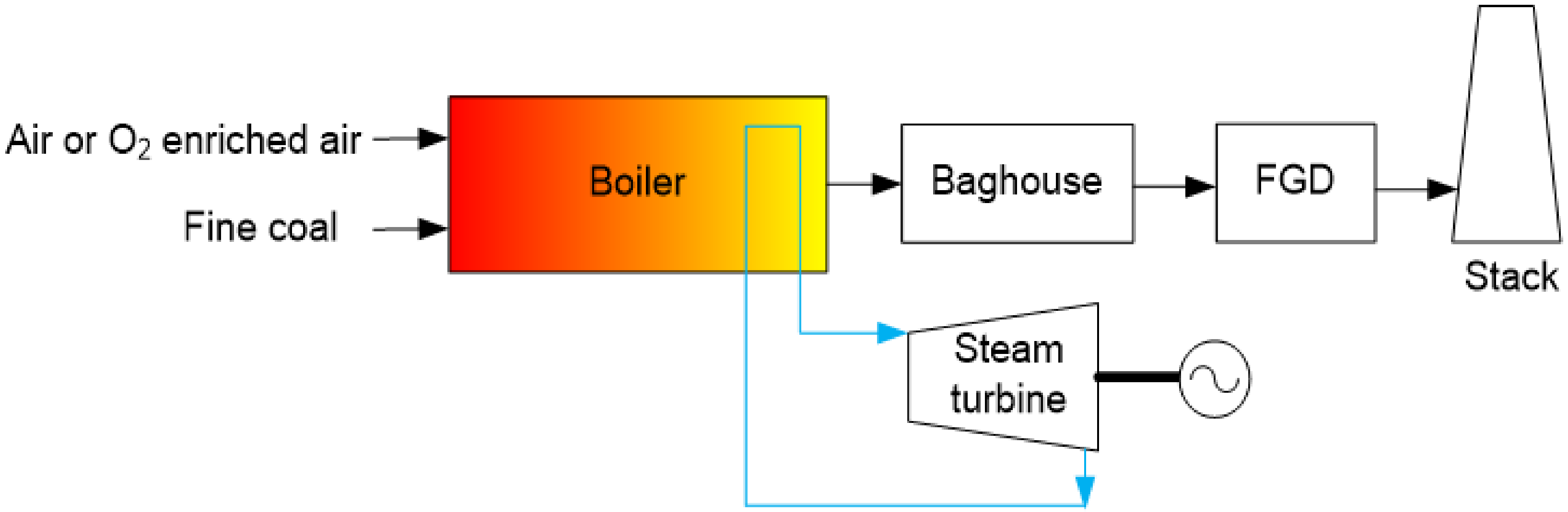


- 6~8% of the energy in mined coal lies in the less than 150 µm particle size fraction.[1]
- There is up to 80 wt% water in slurry after flotation, so it is hard to burn.
- It is very difficult to reduce the water content to 20 wt% or less due to the small particle size. Many technologies have been studied for dewatering: vacuum filtration, hyperbaric filtration, and centrifugal filtration. However, their operating cost is high.
- Every year, U.S. coal producers discard about 70~90 million tons of fresh fine coal. In the U.S., there are already approximately 4 billion tons of fine coal waste in ponds.[2]
- With a disposal cost of $11 per ton[3], $ 44 billion will be needed to dispose of the existing fine coal.

1. Patwardhan, A., *et al*., Coal Preparation, 2006. **26**(1): p. 33-54.
2. https://www.osti.gov/servlets/purl/1422998
3. https://www.arippa.org

TDA’s Approach





TDA’s approach does not require the dewatering step and the wet fine coal can be directly combusted.

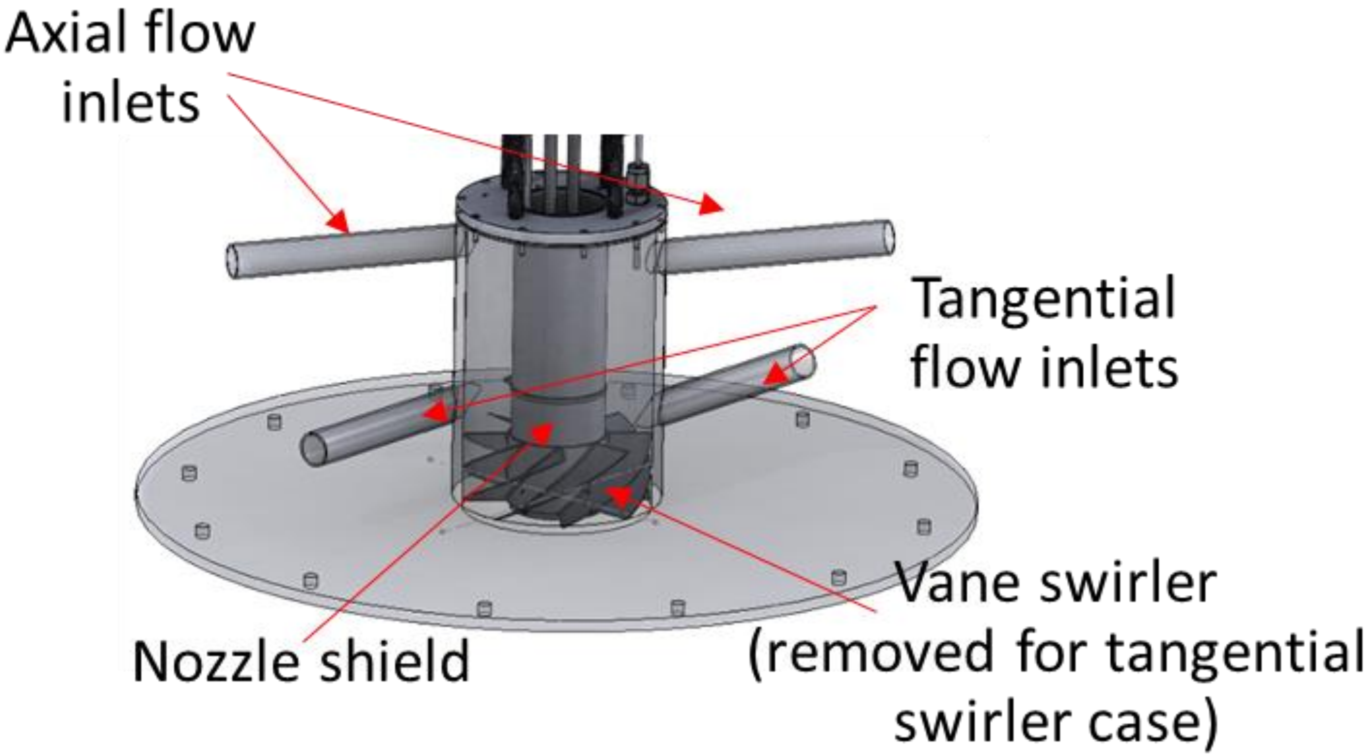
Coal Water Slurry Preparation

- The slurry was made from real fine coal.
- 100-g samples were made to characterize the slurry.
- Solids loading of 62.5%
- Viscosity of about 300 cP at 132 1/s shear rate.
- Pumpable.
- The production was scaled up to 18 kg per batch.

Atomization

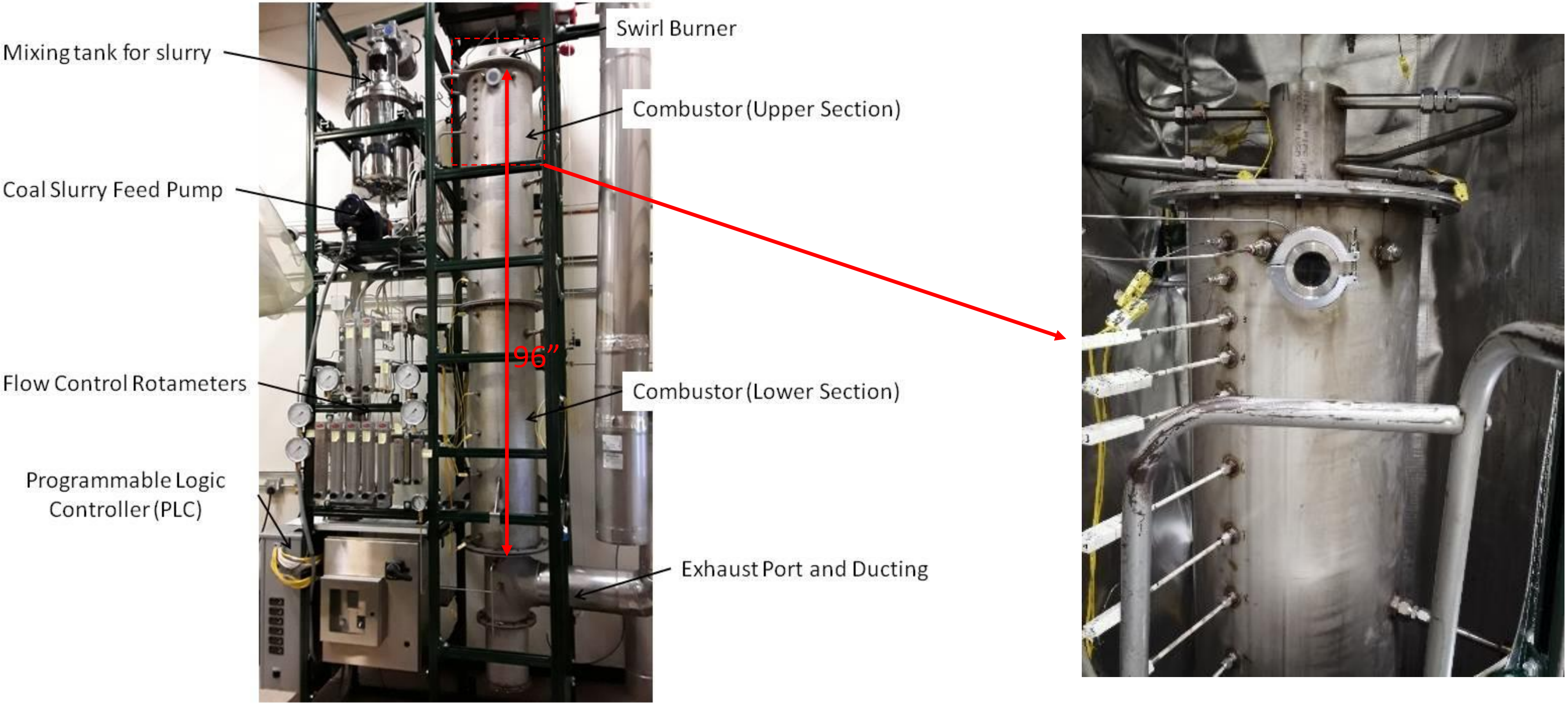
- The fine atomization needed for direct combustion was achieved using two-fluid nozzles.

Bench-scale Burner



The burner can be configured to use either a tangential or vane swirler.

Combustion Rig

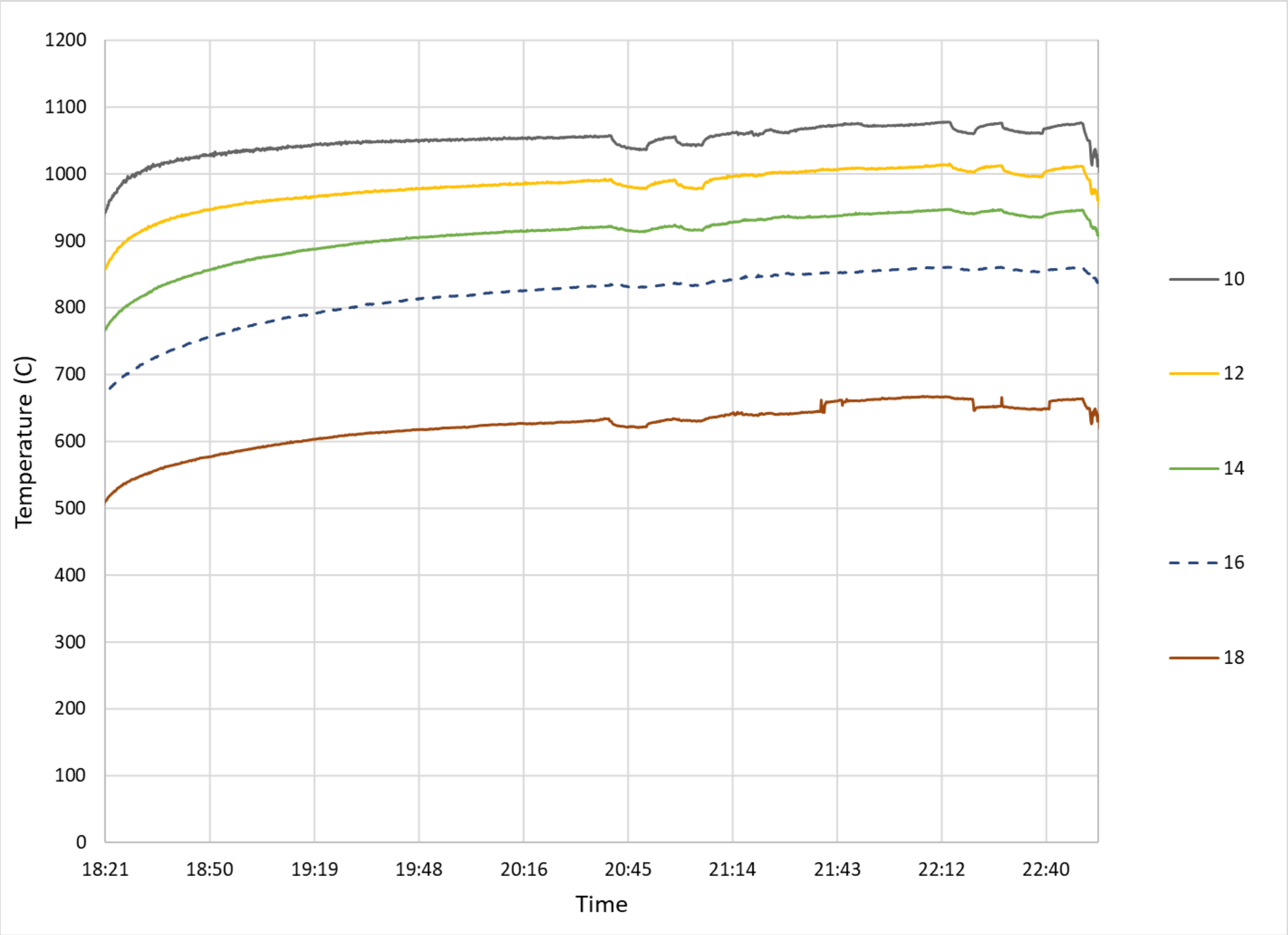


- New construction at TDA (up to 25kW thermal)
- 8.25” ID x 96” H combustion chamber

Combustion Experiments

- Demonstrated self-sustained and continuous flame burning slurry
- Air combustion – no oxygen enrichment required
- About 17 kW thermal output
- Flue gas cooled by spray-quench tower downstream of the combustor
- Achieved 95% burnout for coal

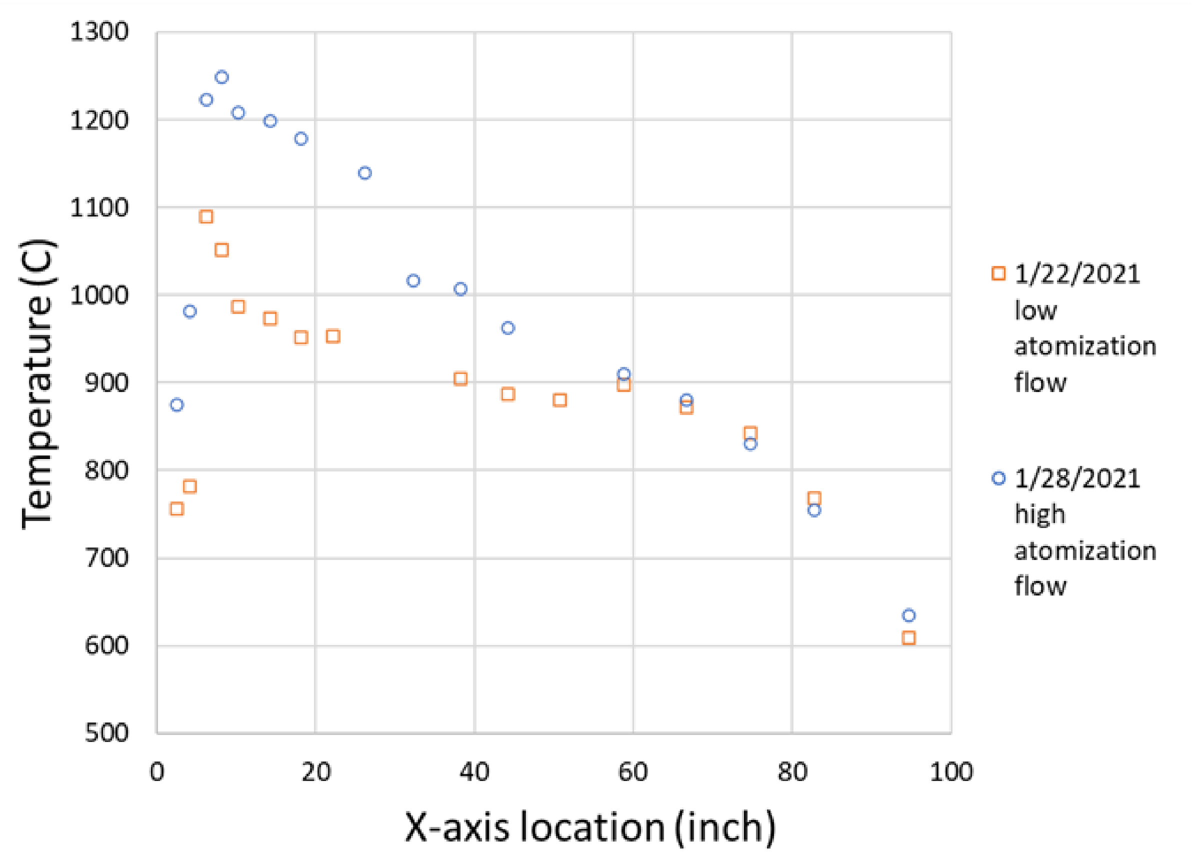
Ash sample



Wall temperature on 4/2/2021

Effect of Atomization on Flame

- Tangential swirler was used (30% swirl).
- High atomization flow generates finer droplets.
- The better atomization case has higher wall temperature for the upper section and higher burnout.



The wall temperature profiles for two atomization conditions

Effect of Swirler Type

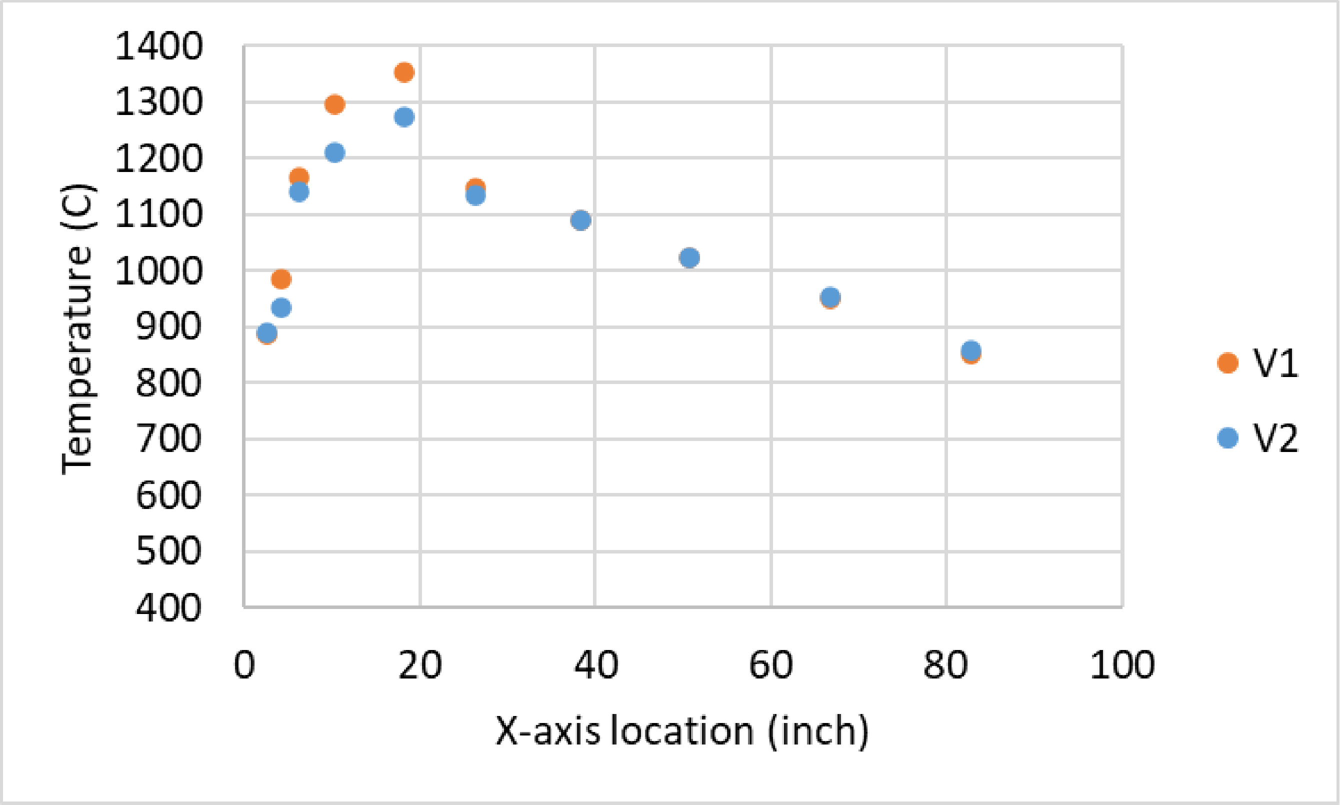
- Both swirlers can achieve a stable flame and high coal burnout.
- Ash was found deposited on the inner wall of the upper section of the combustor. The tangential swirler case has more deposition. Thus, the vane swirler is more advantageous.
- Subsequent studies focused on vane swirler.

Effect of Swirler Intensity

V1

V2

- The angle between the vane and axis for V1 is larger, which increases the swirl intensity.
- The temperature in the flame zone for V1 case was higher.

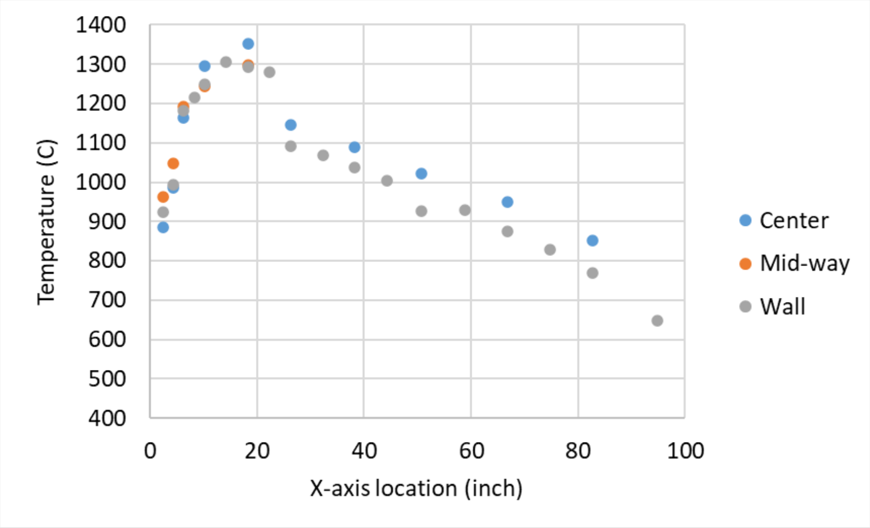


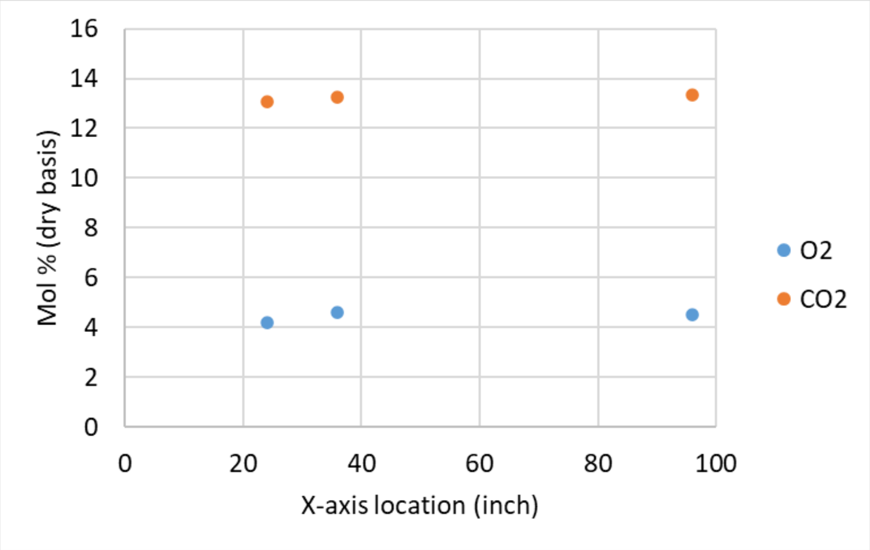
The center temperature profiles for two vane swirler cases

Flame Shape

V1 vane swirler case results (4/8/2021)

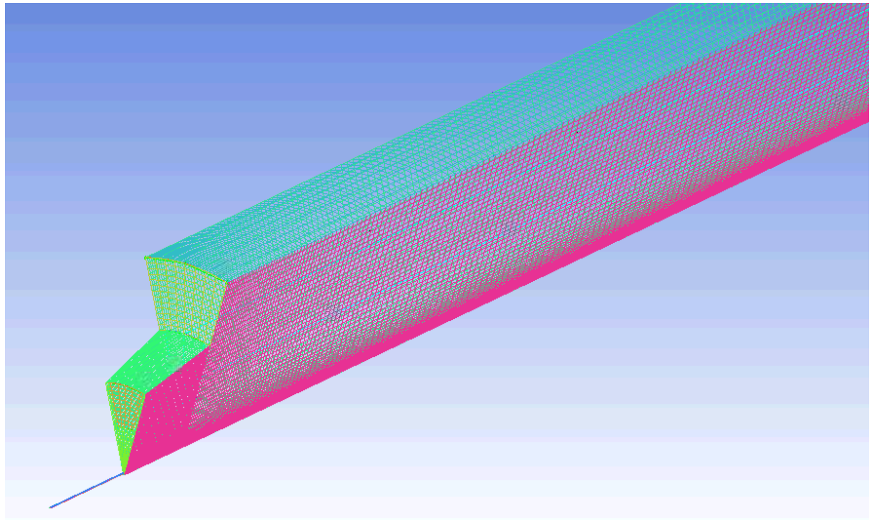
- The quick temperature ramping along the x-axis downstream the nozzle reflects strong mixing and intensive reaction.
- Lower center temperature in the region downstream of the nozzle indicates spray jet.
- Most reaction is completed at ¼ of the total height of the combustor.

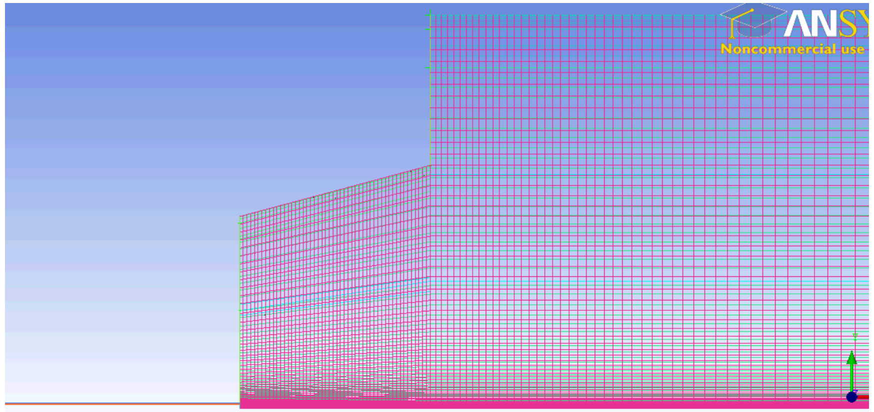




CFD simulation

Mesh drawing



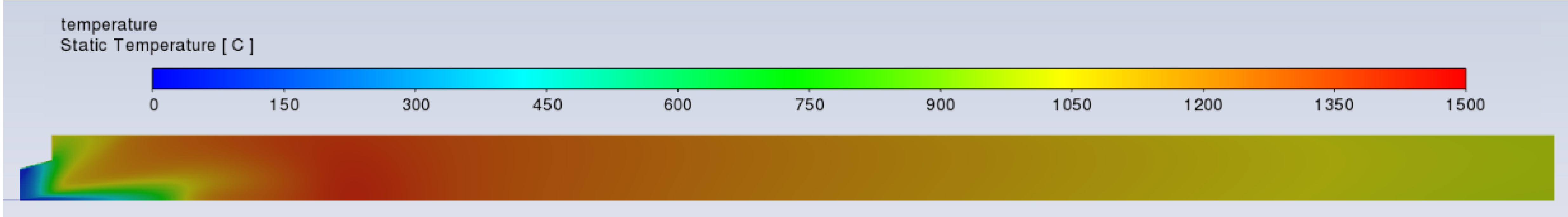


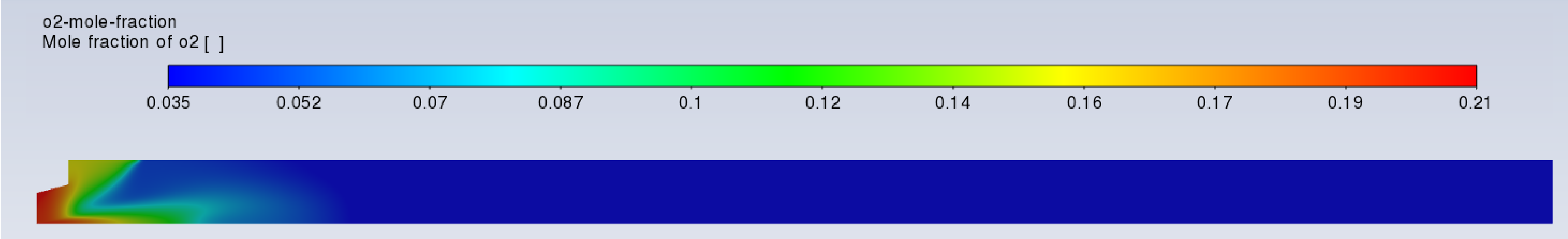
Major simulation assumptions:

- Periodic boundary condition
- Shear-stress transport k-ω model for turbulence
- Two-step global reaction mechanism for coal oxidation
- No volume change for individual coal particles before and after evaporation
- Rosin–Rammler distribution for droplets
- Chemical Percolation Devolatilization model for devolatilization
- Kinetic-diffusion controlled char combustion model
- Radiation considered

This part of the work was conducted in collaboration with Washington University in St. Louis.

CFD simulation





The simulated results agreed well with the experiments.

Techno-economic Analysis

- We are analyzing a case of retrofitting an existing 80 MWe power plant.
- The existing circulating fluidized bed is assumed to be replaced by TDA's boiler.
- Existing equipment is used as much as possible.
- The entire plant is simulated in Thermoflex.
- Site characteristics and emission requirements are based on the existing plant.

This part of the work is was conducted in collaboration with University of California, Irvine.

Summary

1. Pumpable coal water slurries were made using real fine coal from a coal mine partner.
2. Fine sprays were achieved, and the slurry can be directly combusted.
3. Production was scaled up to 18 kg per batch.
4. An bench-scale combustion rig was constructed at TDA. The burner can use either a tangential or vane swirler.
5. The continuous and self-sustained slurry flame was achieved under air firing. The flame had high coal burnout.
6. Fine atomization is required for both ignition and high conversion.
7. Less deposition on the inner wall was found for vane swirler case than for the tangential swirler case.
8. The flame zone had a higher temperature with a stronger intensity swirler design.
9. The flame shape was determined from temperature and composition data.

Summary (cont'd)

10. A CFD model for the slurry combustion process was developed. There was good agreement between the simulated and experimental results.
11. A TEA is under investigation for retrofit installation at a 80 MWe power plant.

Acknowledgement

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