



The Practical Use of CFD in Burner Development and Boiler Applications

Matthew Martin
ClearSign Technologies



**MARCH 31-
APRIL 2
2026**



**GAYLORD
OPRYLAND**

at The Legendary

**ABMA
BOILER
EXPO 2026**

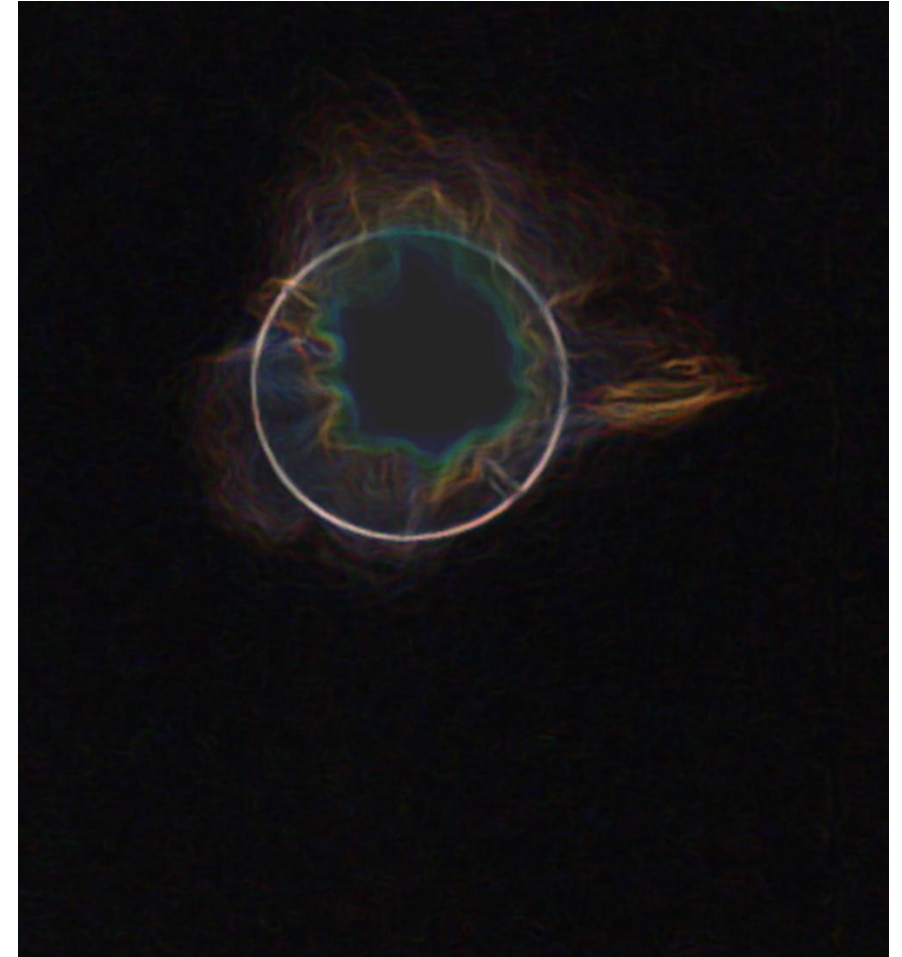
ABMA
LEADERSHIP FOR THE BOILER INDUSTRY



The Practical Use of CFD in Burner Development and Boiler Applications



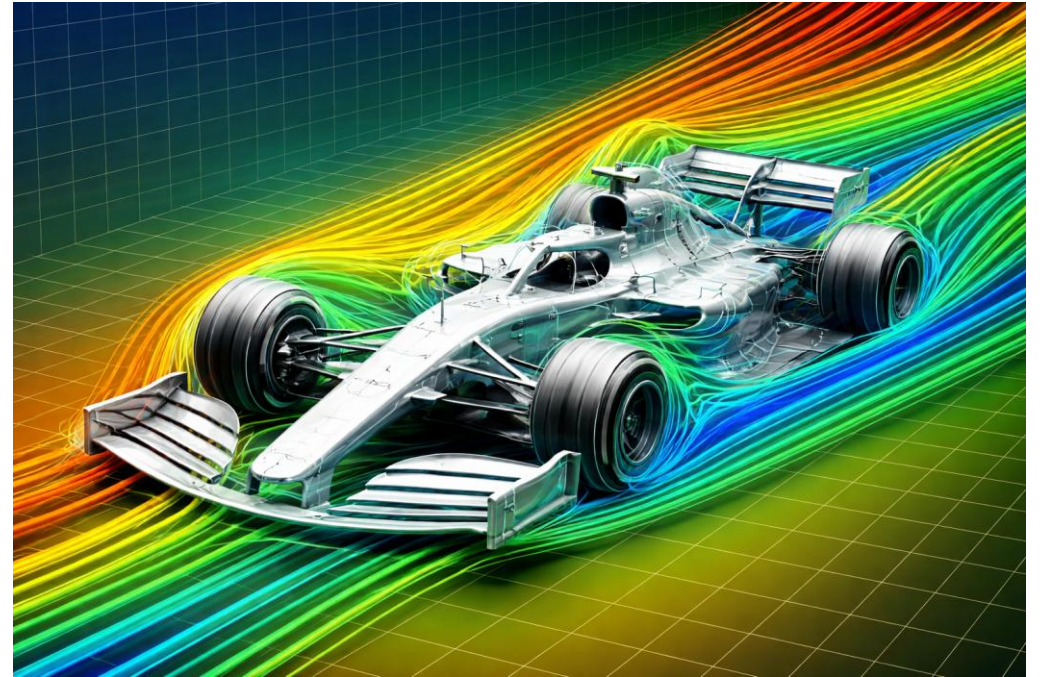
- What is Computational Fluid Dynamics (CFD)?
- CFD: A brief history in boilers and burners
- Why use CFD in burner development?
- Why use CFD for boiler applications?
- Examples
- Summary



What is CFD?



- A virtual wind tunnel
- The solution of partial differential equations
 - Navier-Stokes
 - Turbulence
 - Radiation
 - Chemistry
- *Usually*, industrial CFD is
 - Steady-state
 - Finite-volume
 - Modeled turbulence
- Used to tell us what the fluid flow is going to do given a design and a set of boundary conditions

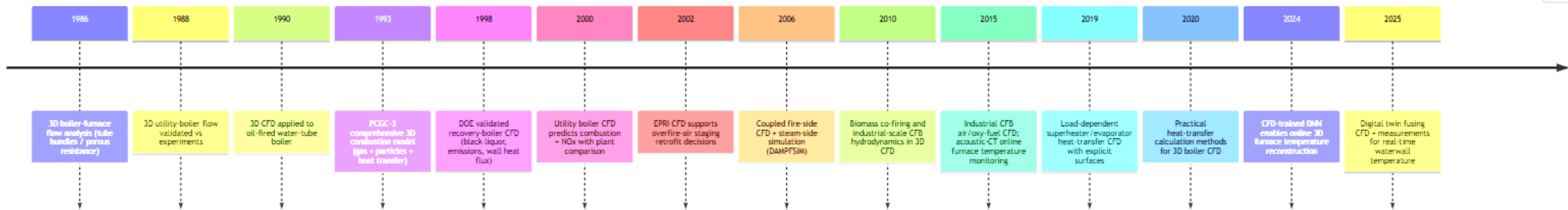


CFD History – Boilers and Burners



- A non-exhaustive literature survey suggests that boiler CFD modeling started from the largest scales
- Conversely burner modeling history suggests the smallest details were investigated first

CFD in Boilers – selected milestones

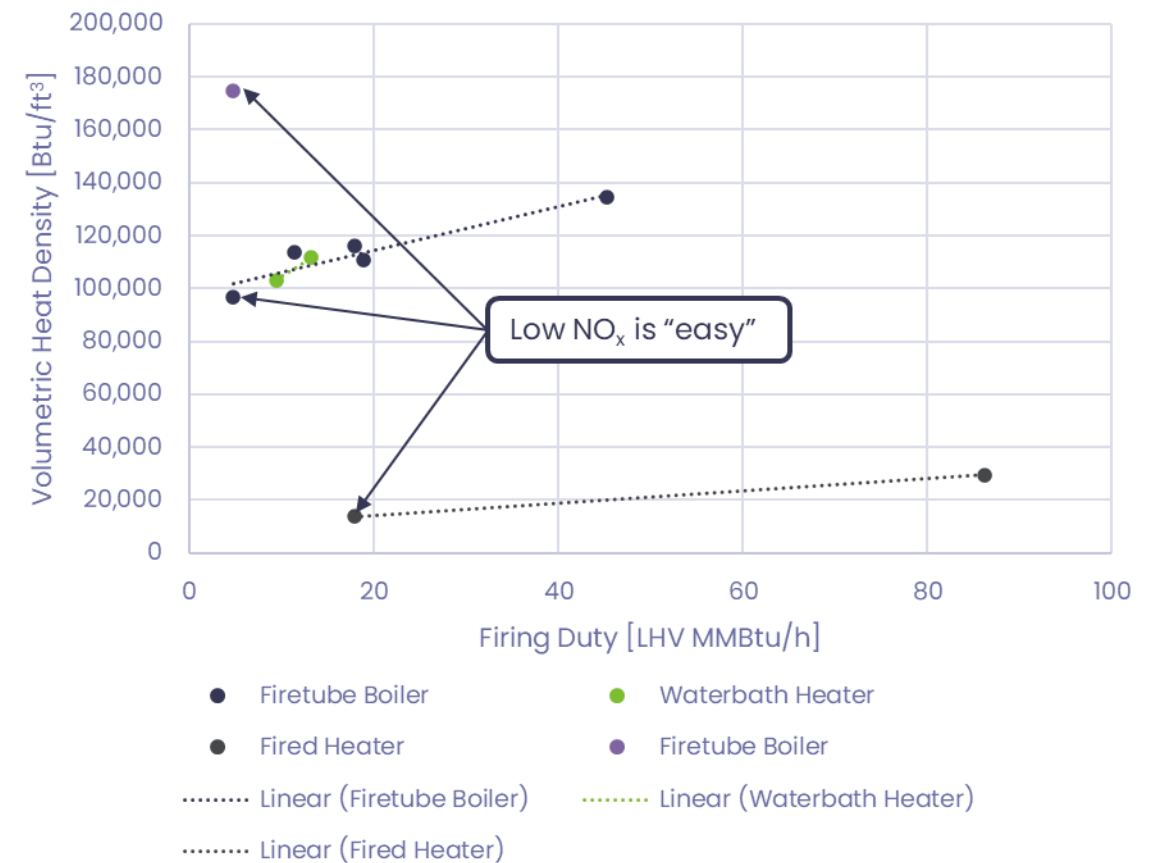


Burner Firing Environment



- Burner performance is affected by volumetric heat density
 - NO_x
 - Flame characteristics
- Prior versions of API 560 limited to 16,000 Btu/h-ft²
- Still many poor performing installations

Volumetric Heat Density vs Burner Fired Duty for Various Equipment

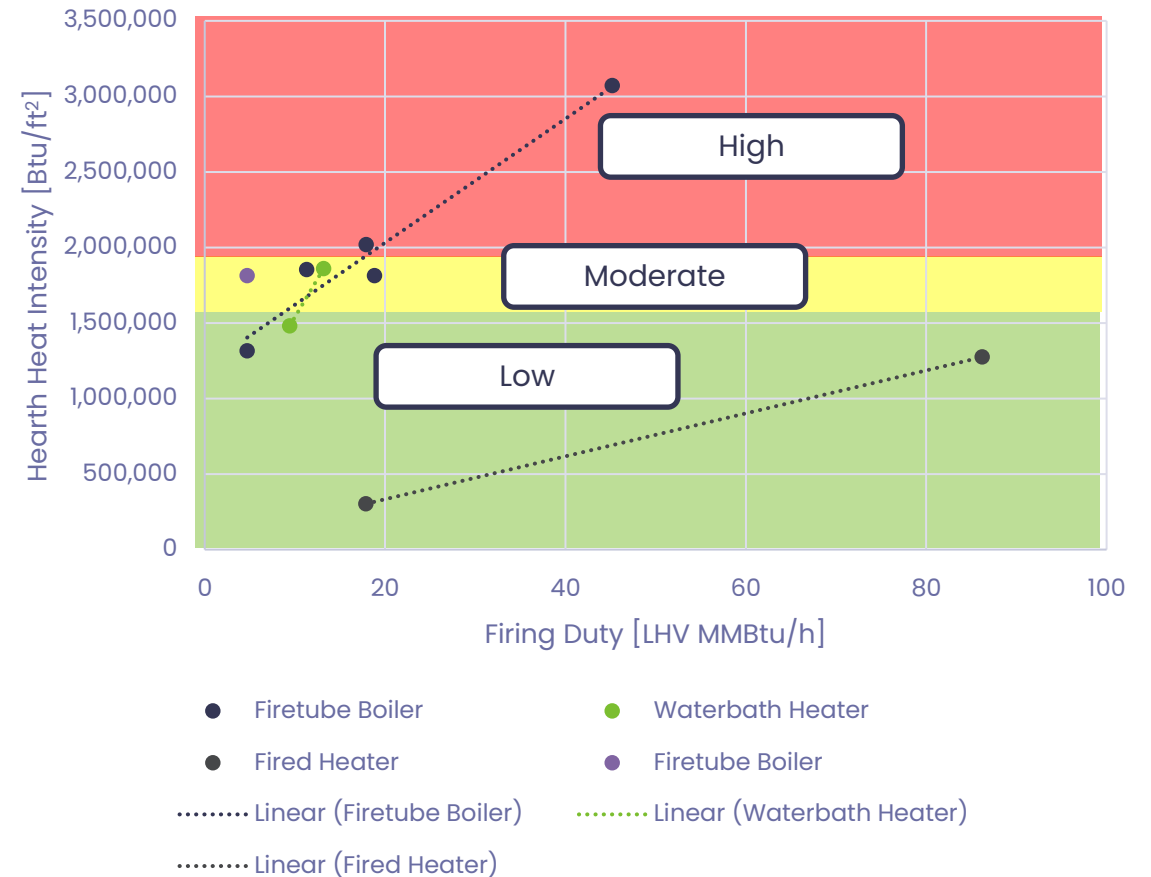


Burner Firing Environment



- A different metric improves screening
 - Fired duty / Burner mounting wall area
- Adopted by API 560
 - Limit 300,000 Btu/h-ft²
 - Not plausible for boilers!

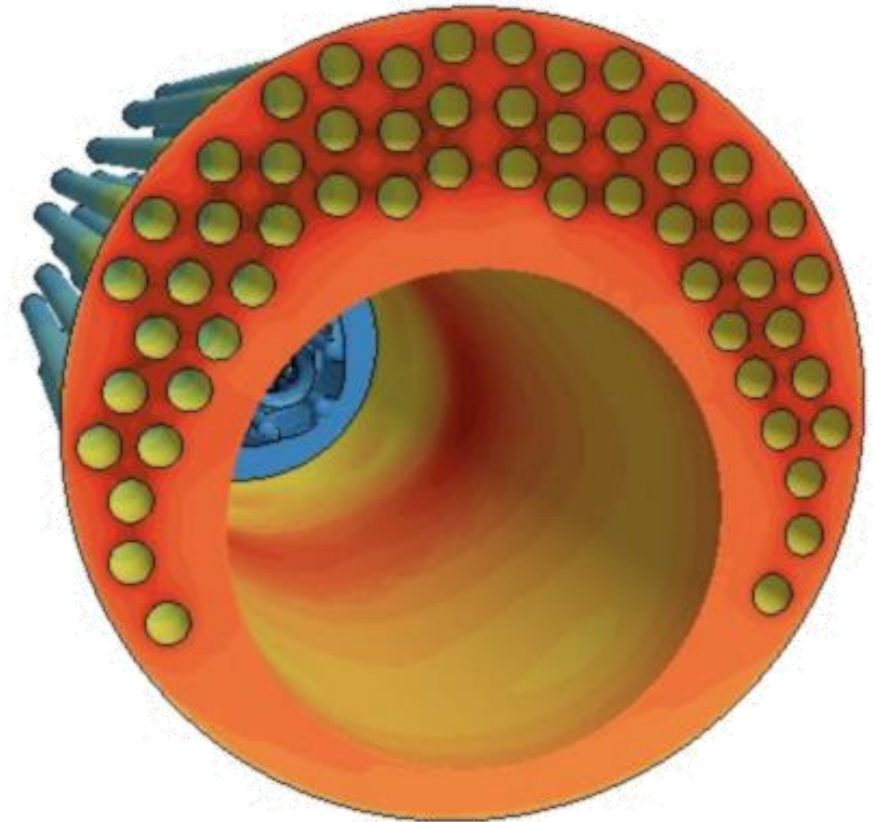
Hearth Heat Intensity vs Burner Fired Duty for Various Equipment



CFD for Burner Design



- Limitations of physical testing
 - Cannot test every boiler design
 - Cannot test every heat release
 - Iterative design is relatively expensive



Virtual Burner Design is Possible

CFD-First Burner Design Example



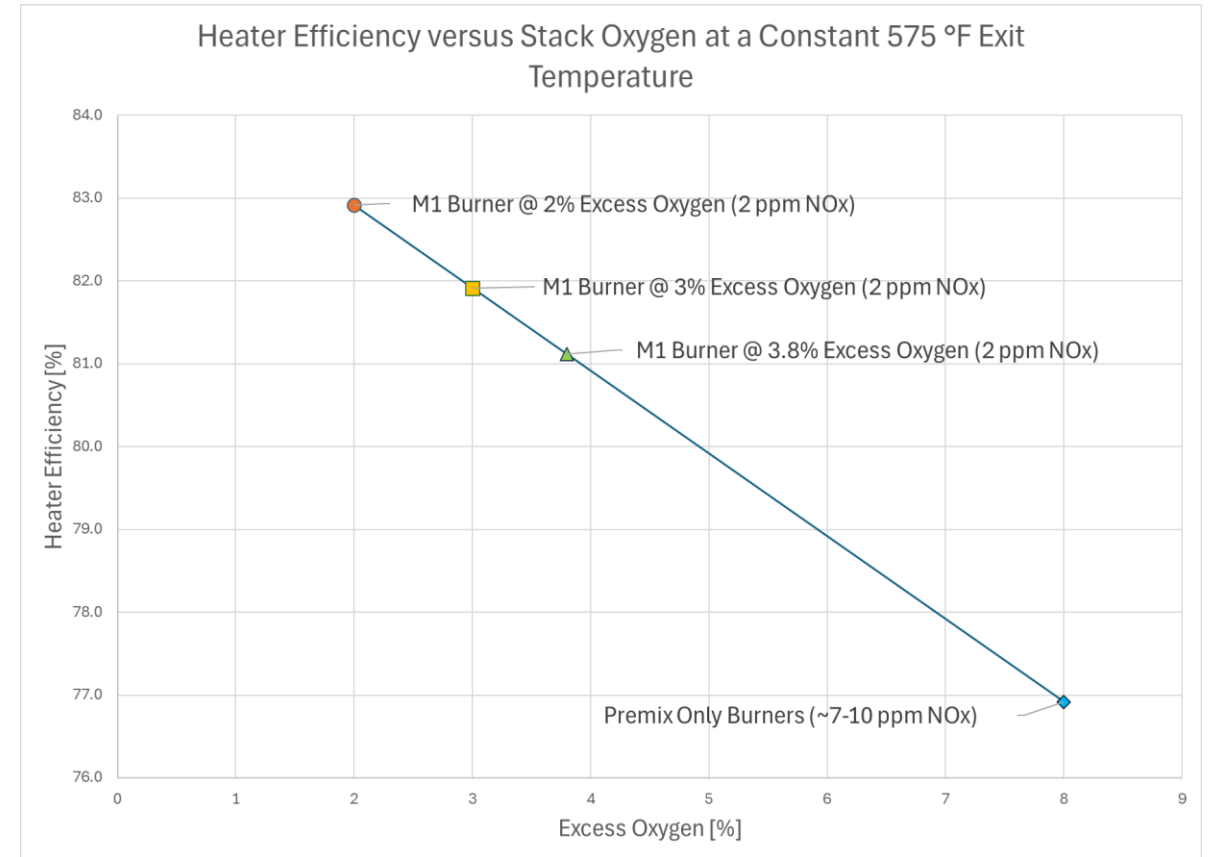
- Project Goals
 - Low excess air operation
 - Low NO_x operation
 - Shorter flames
 - Increased efficiency
 - No physical testing



Why not High Excess Air?



- Heat transfer
- Premixed combustion
 - Fuel lean → Lower NO_x
 - Too lean → Unstable combustion (100% Excess Air)
- Practically not achieving performance



High Excess Air *Only* is not Practical

A Step Change in Performance

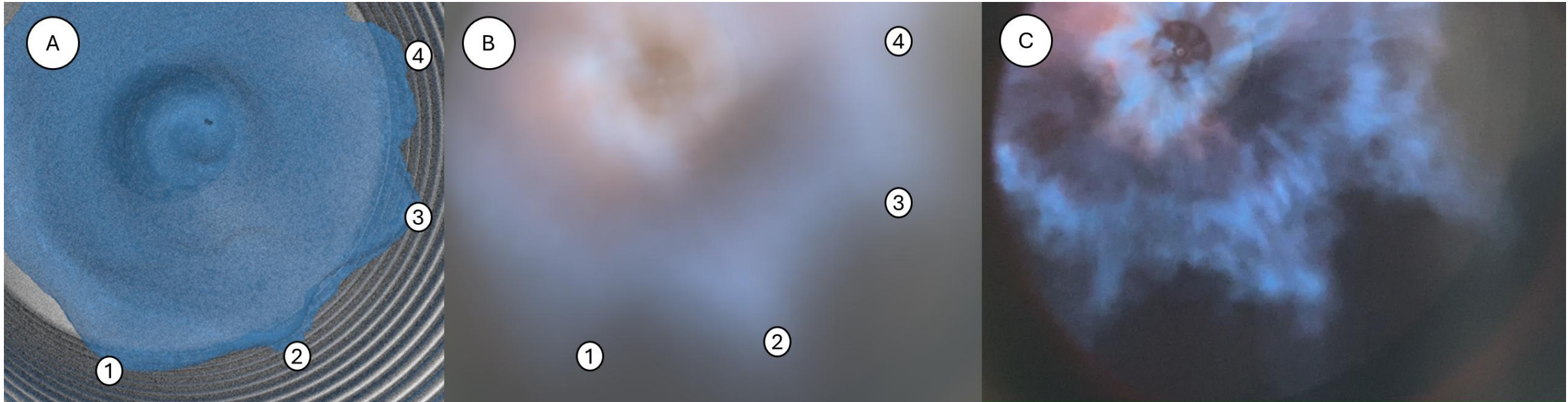


Point	Heat Release [MMBtu/h]	CO [ppm @ 3% O ₂]	NOx [ppm @ 3% O ₂]	Oxygen [% Dry]
1	10.92	145.00	6.00	3.10
2	12.74	5.00	5.00	3.10
3	14.56	0.00	4.00	3.00
4	16.38	0.00	3.00	3.10
5	18.20	0.00	3.00	3.10
6	14.56*	0.00	2.00	3.00

* Tertiary fuel circuit activated.

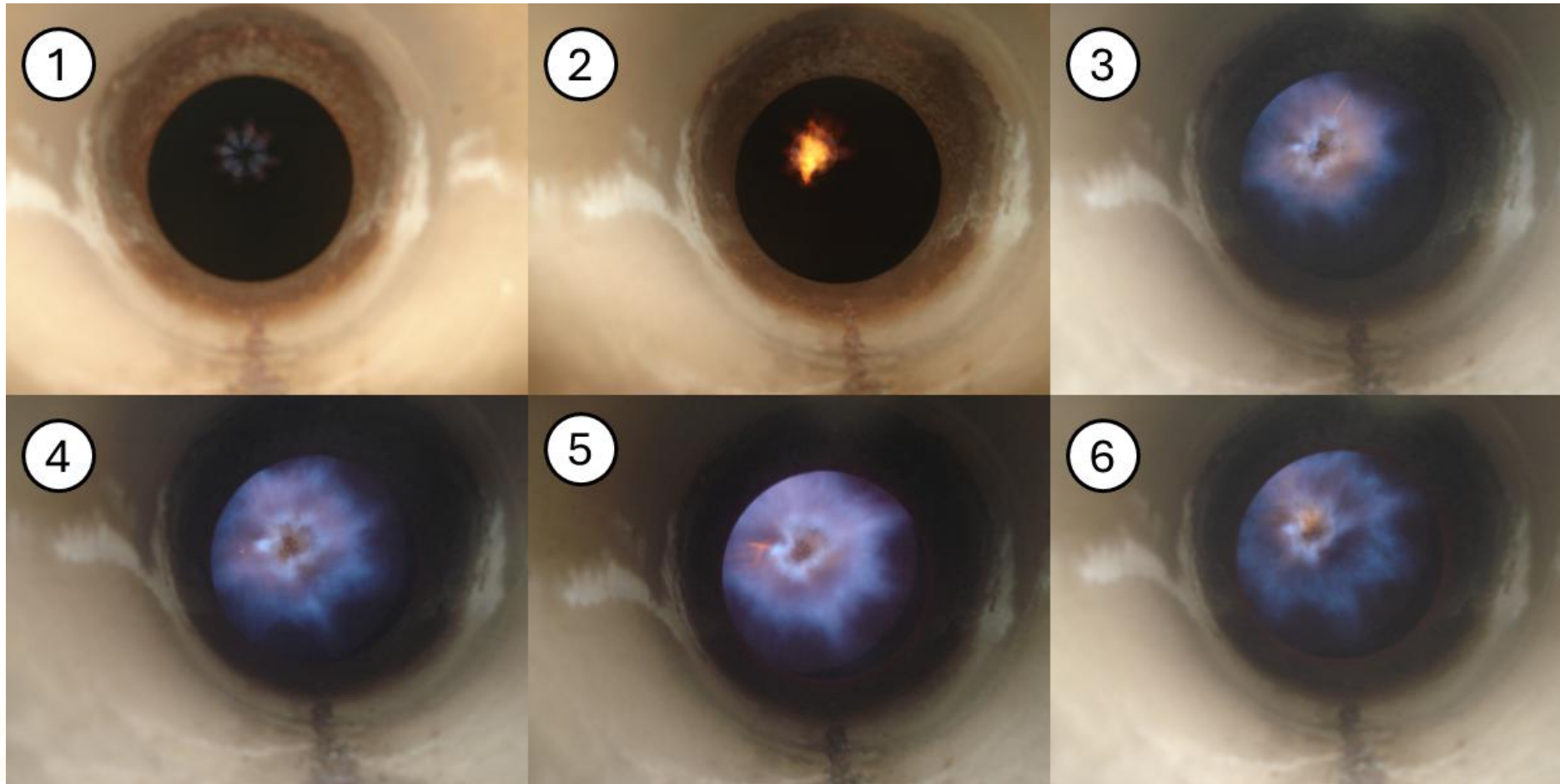
Less than 2.5 ppm NO_x in a Practical Application without Special Controls

CFD Simulation – Flame Shape

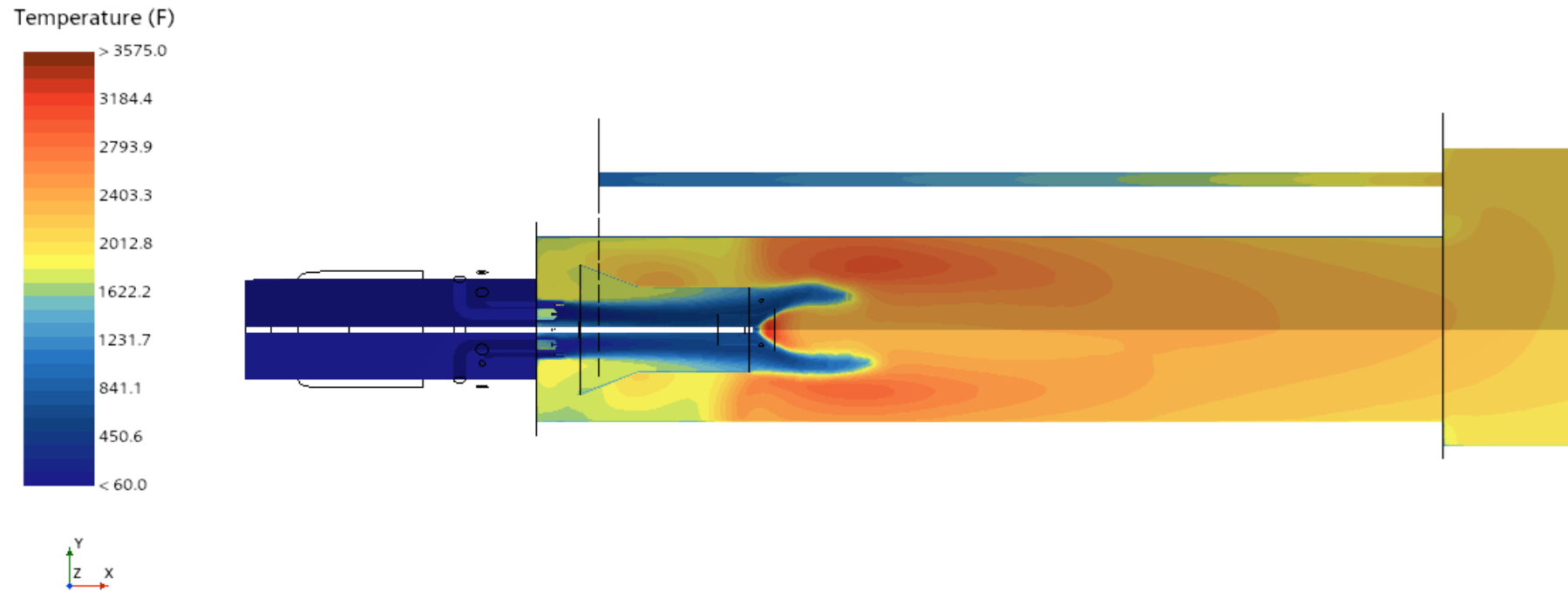


Steady-State Simulation Reproduces Flame Shape

Burner Flame at Various Rates



CFD Simulation – Firetube Boiler



Predicted < 2.5 ppm (@ 3% Excess Oxygen) in a Firetube Boiler

Design Permutations, Combinations, and Iterations



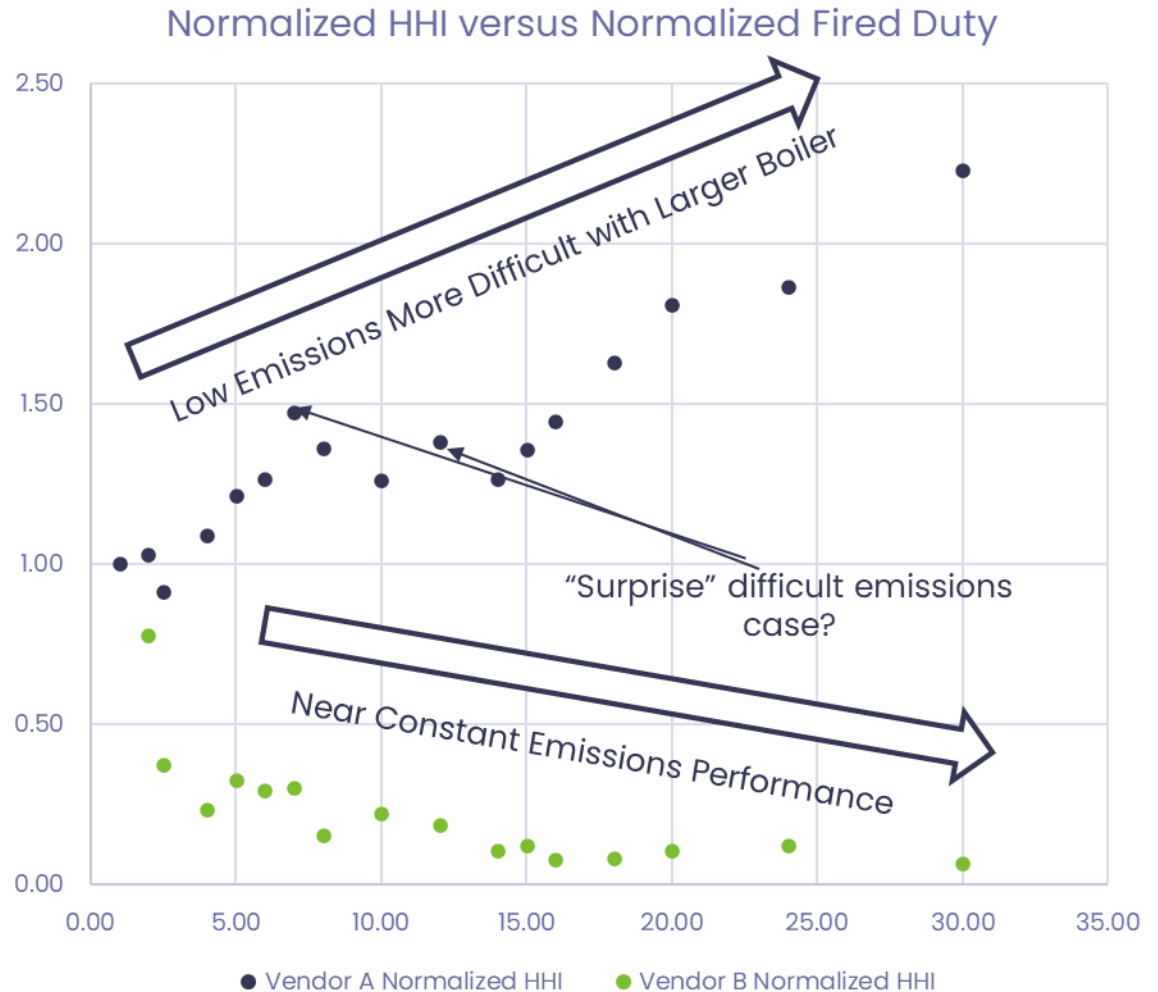
- Rapid prototyping of burner designs made possible
- Relatively detailed and accurate assessment of burner design is possible
- Burner-to-boiler interaction is simulated

CFD Stack Oxygen [% Dry]	Swirler Fuel	NOx Reducing Steam	First Pass Efficiency [%]	cCO [ppm]	cNOx [ppm]
5.28%	LOW	HIGH	67.83	0.02	2.46
5.77%	LOW	HIGH	68.71	0.03	1.42
6.00%	HIGH	MEDIUM	67.46	0.02	2.17
7.77%	HIGH	LOW	64.98	0.01	2.32
7.75%	LOW	MEDIUM	63.34	0.05	2.73
7.38%	LOW	LOW	62.86	0.53	3.24
7.40%	LOW	LOW	62.96	0.56	3.05

CFD for Boiler Applications



- Why use CFD on a *per application* basis?
 - Wide variety of boiler designs
 - Determine feasibility for edge cases
 - Risk mitigation for early adopters
 - Custom design for special requirements



Summary



CFD Simulations for Burners and Boilers

- Computational Fluid Dynamics (CFD) is well-tested for boiler and burner development
- Improved and custom burners can be developed rapidly
- Not all boilers are the same!
- Boiler design affects burner performance
- Per-application CFD
 - Reduces risk for early adopters
 - Reduces risk for burner-boiler interaction in unseen combinations
 - Improves success rate for edge cases

CFD Provides
Reduced Risk
SCR-Free
Implementations



**Boost
Operational
Efficiency**



**Reduce
Costs**



**Decrease
NOx
Emissions**



www.clearsign.com