# Combustion of Hydrogen rich fuels in process heaters

Influence on thermal performance, emissions, and safety aspects


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26 May 2023

# Definitions & cautionary note

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Shell's operating plan, outlook and budgets are forecasted for a ten-year period and are updated every year. They reflect the current economic environment and what we can reasonably expect to see over the next ten years. Accordingly, they reflect our Scope 1, Scope 2 and Net Carbon Footprint (NCF) targets over the next ten years. However, Shell's operating plans cannot reflect our 2050 net-zero emissions target and 2035 NCF target, as these targets are currently outside our planning period. In the future, as society moves towards net-zero emissions, we expect Shell's operating plans to reflect this movement. However, if society is not net zero in 2050, as of today, there would be significant risk that Shell may not meet this target.

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This presentation may contain certain forward-looking non-GAAP measures. We are unable to provide a reconciliation of these forward-looking Non-GAAP measures to the most comparable GAAP financial measures because certain information needed to reconcile those Non-GAAP measures to the most comparable GAAP financial measures is dependent on future events some of which are outside the control of Shell, such as oil and gas prices, interest rates and exchange rates. Moreover, estimating such GAAP measures with the required precision necessary to provide a meaningful reconciliation is extremely difficult and could not be accomplished without unreasonable effort. Non-GAAP measures in respect of future periods which cannot be reconciled to the most comparable GAAP financial measure are calculated in a manner which is consistent with the accounting policies applied in Shell plc's consolidated financial statements.

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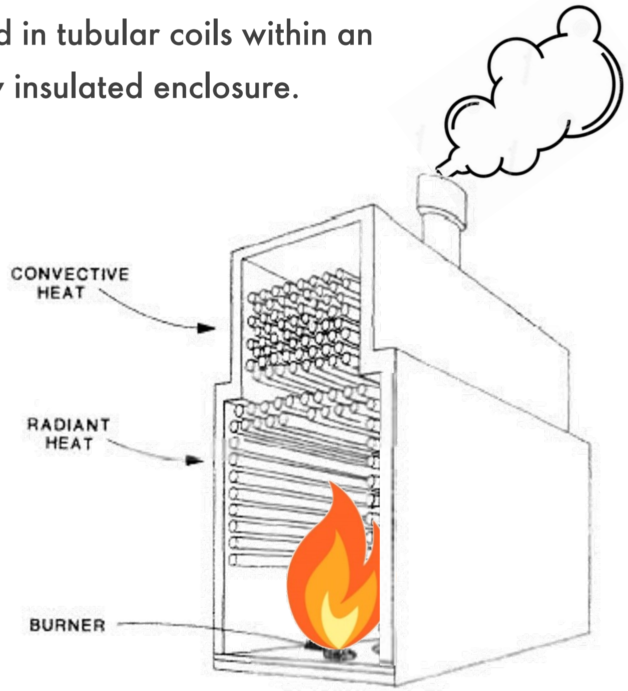
# About me

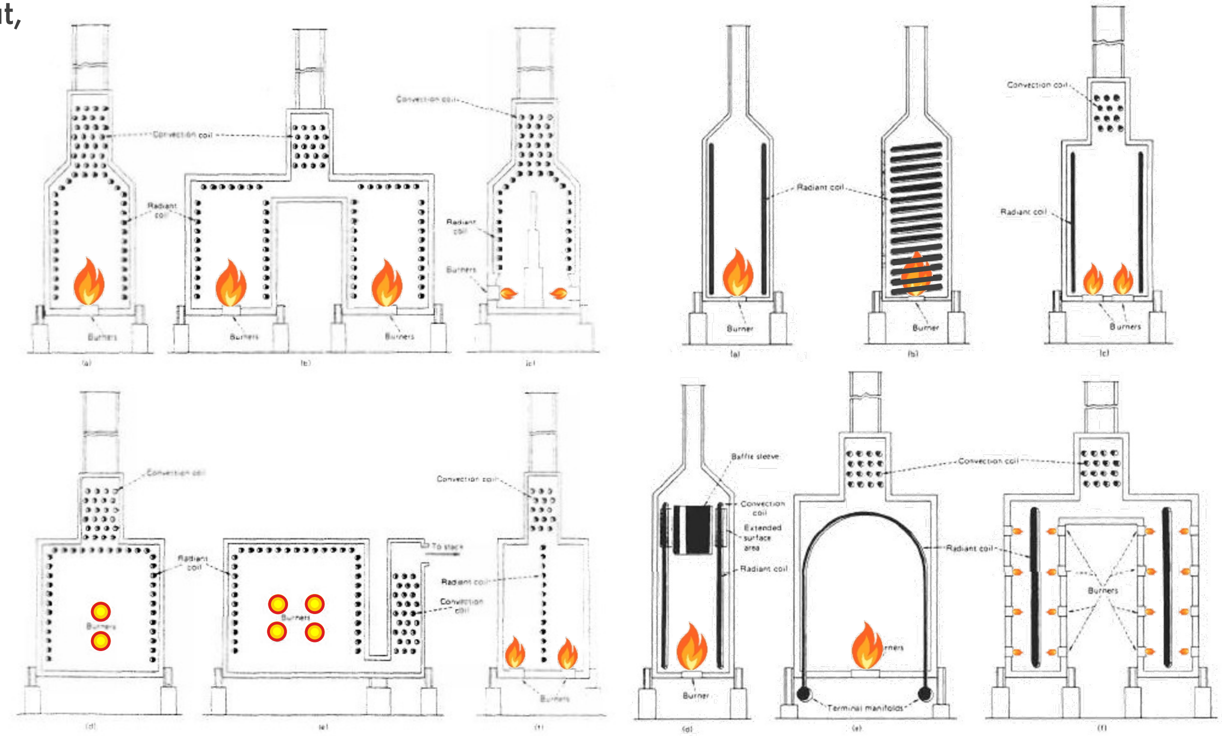
**STEFANO MANIA**
**SENIOR HEAT TRANSFER ENGINEER**
**SHELL GLOBAL SOLUTIONS INTERNATIONAL B.V.**
**ENERGY TRANSITION CAMPUS AMSTERDAM**

- 18 years in the industry
- Global SME for FD furnaces and Burners
- Technical focal point for safe H2 firing
- API/ISO reviewer/member, currently working in:
  - Development of the new standard ISO5133 “protective systems for Fired Heaters” replacing EN746
  - Support for revision of the new edition of API560, API561, API535 and API556
- I am Italian (born and raised in the sunny Sicily island)
- I have two boys aged 12 and 11 years old
- I play the piano and practice Jujitsu martial art since I was a little kid
- I have recently started a new hobby enjoying fishing with my sons

# What is a Process Fired Heater

API560 defines a process heater as an equipment where heat, liberated by the combustion of fuels is transferred to fluids contained in tubular coils within an internally insulated enclosure.

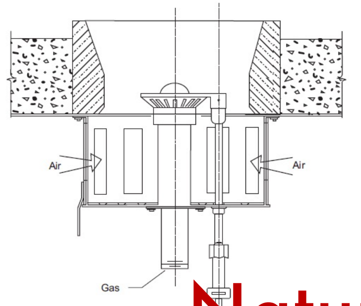


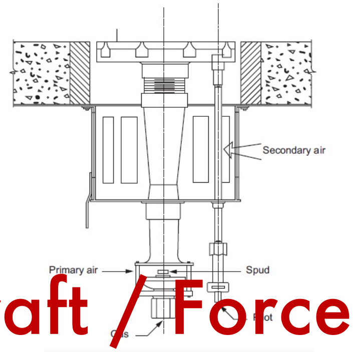



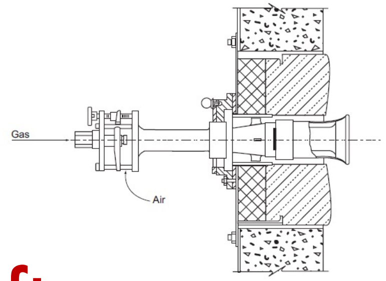
# What is a Process Burner

API535 defines a process burner as a device for the introduction of fuel and air into a heater at the desired velocities, turbulence, and air/fuel ratio to establish and maintain ignition and stable combustion.

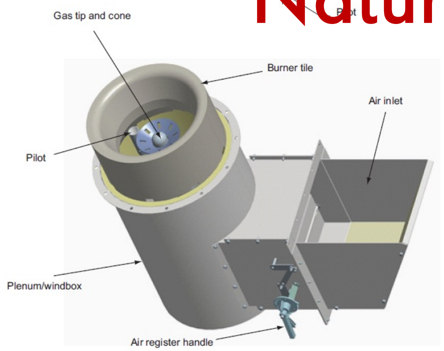
| Raw gas burners | Premix gas Burners | |
|---|---|---|
| Diffusive flame | Straight flame | Radiant wall flame |

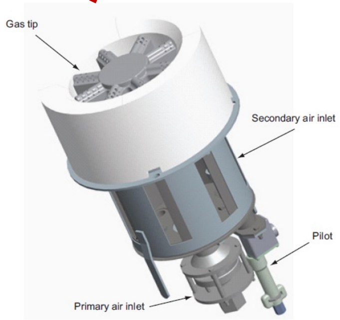


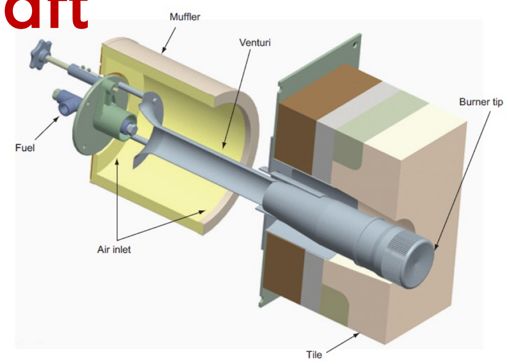




Natural Draft / Forced Draft



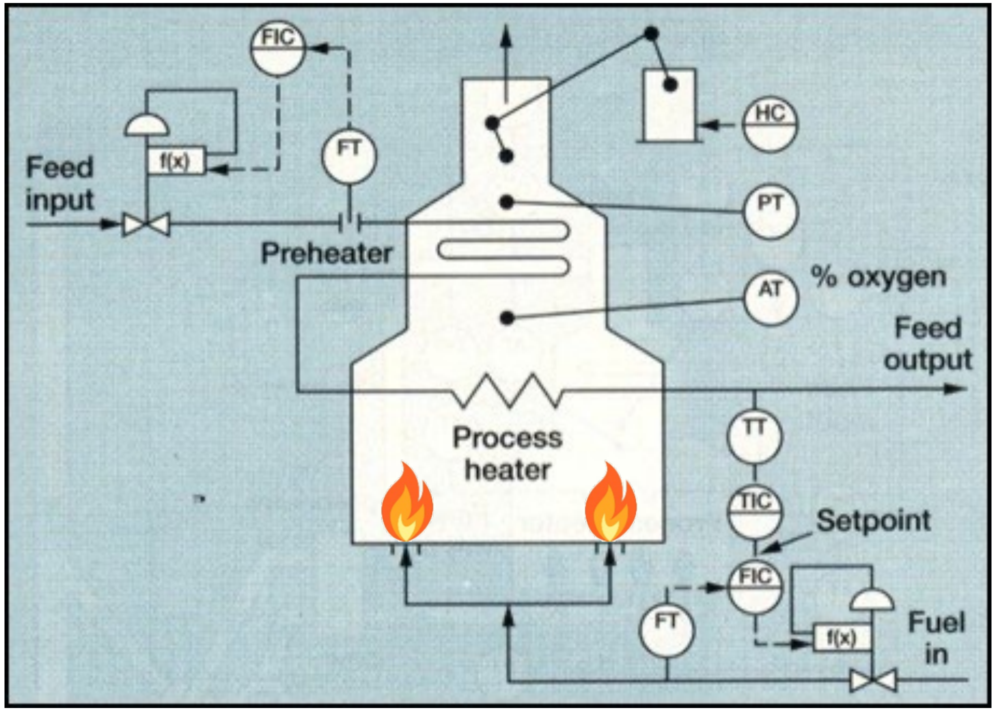




Ref: John Zink Hamworty Combustion Handbook

# How Fired Process Heaters work & Furnace Flooding Hazard

The process outlet temperature controls the amount of fuel fired by the burners.

Lower temperature calls for more fuel and vice versa.

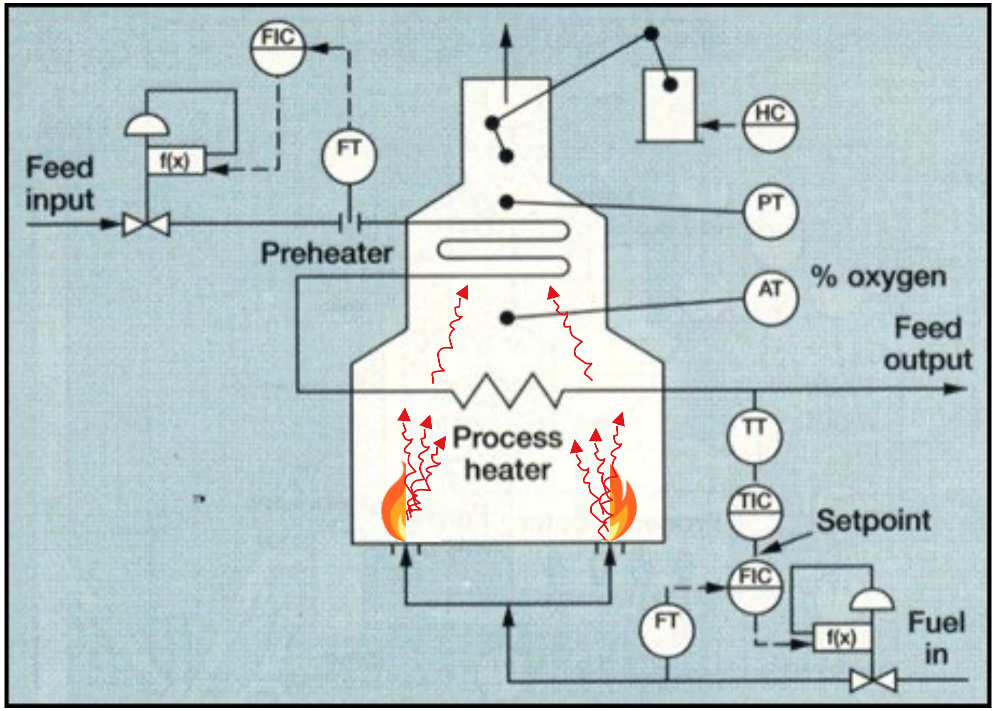


# How Fired Process Heaters work & Furnace Flooding Hazard

If flame instability occurs, part of fuel is not fired and does not transfer heat to the process coils anymore and the unburned fuel accumulates in the firebox.
This produces a drop of the process outlet temperature, and the control loop will respond by adding more fuel worsening the situation.

This process, the increasing accumulation of unburned fuel in the firebox is called “Furnace Flooding” (or Furnace Bogging).

If not properly controlled and safeguarded, a furnace flooding loop could escalate to serious process safety incidents including furnace explosion.



# Furnace Control and Safeguard - Natural Draft Fired Heater

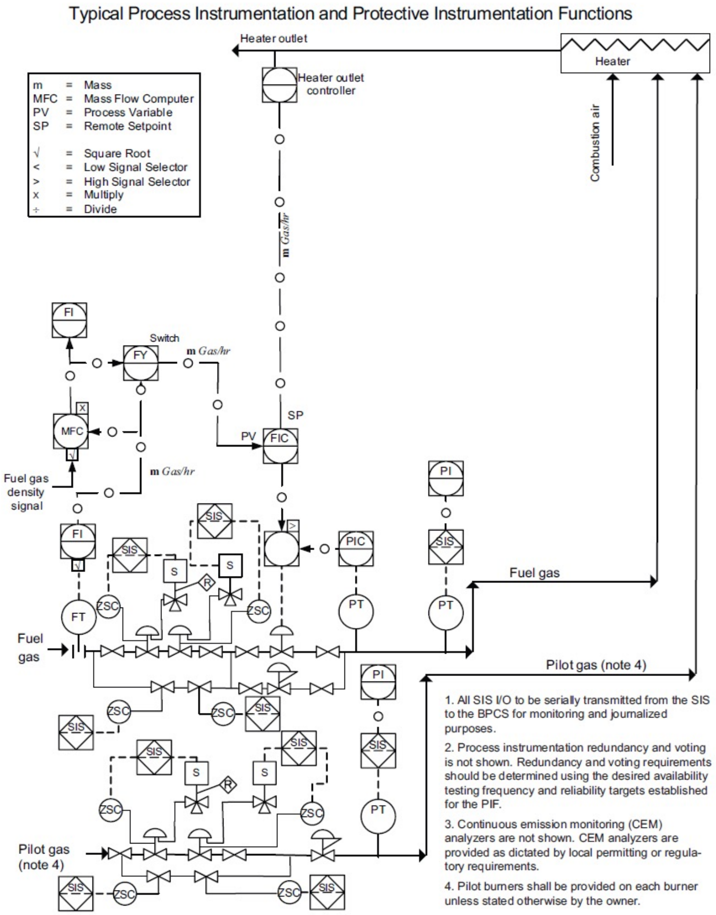



Figure 2—Natural Draft Fired Heater—Fuel Side

## Instrumentation, Control, and Protective Systems for Gas Fired Heaters

API RECOMMENDED PRACTICE 556
SECOND EDITION, APRIL 2011

REAFFIRMED, APRIL 2019

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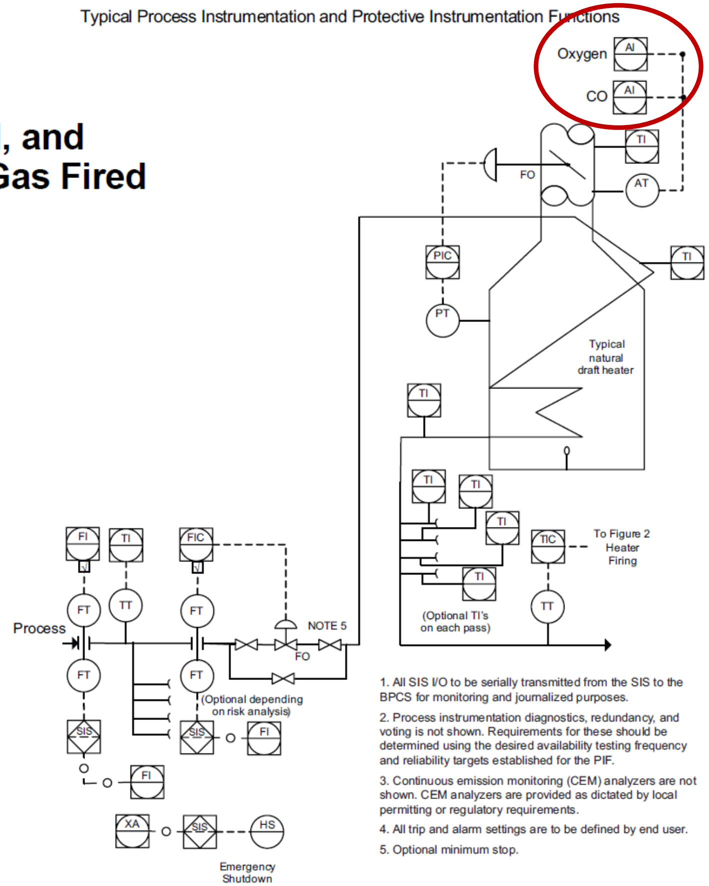


Figure 3—Natural Draft Fired Heater—Process Side

# Flame dimension requirements and flame definition to prevent tubes overheating and flame impingement hazard

## Fired Heaters for General Refinery Service

API STANDARD 560
FIFTH EDITION, FEBRUARY 2016

energy API
AMERICAN PETROLEUM INSTITUTE

### 14 Burners and Auxiliary Equipment

#### 14.1 Burners

**14.1.1** Burner design, selection, spacing, location, installation, and operation shall ensure against flame impingement on tubes, tube supports, and flame exiting the radiant section of the heater throughout the entire operating range of the burners. The location and operation of burners shall ensure complete combustion within the radiant section of the heater.

**14.1.2** Burners shall be designed in accordance with all local and national statutes and regulations.

**14.1.3** For burner clearances, the data given in Table 15 shall be used for natural-draft burners and in Table 16 for forced-draft burners. The tables are based on low $NO_x$ burners that are designed to reduce the formation of $NO_x$ below levels generated during normal combustion in conventional burners.

**14.1.4** In addition to 14.1.3, the following shall apply.

a) The number and size of burners shall ensure that the visible flame length is a maximum of two-thirds of the radiant section height. For floor-fired heaters, the CO content at the bridge wall shall be a maximum of 40 ml/m$^3$ (40 ppm, by volume) for gas-fired heaters, or 80 ml/m$^3$ (80 ppm, by volume) for oil-fired heaters, at maximum design firing conditions.

b) For horizontal opposed firing, the minimum visible clearance between directly opposed firing flame tips shall be 1.2 m (4 ft).

## Burners for Fired Heaters in General Refinery Services

API RECOMMENDED PRACTICE 535
THIRD EDITION, MAY 2014

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### 12.6.6.2 Shape

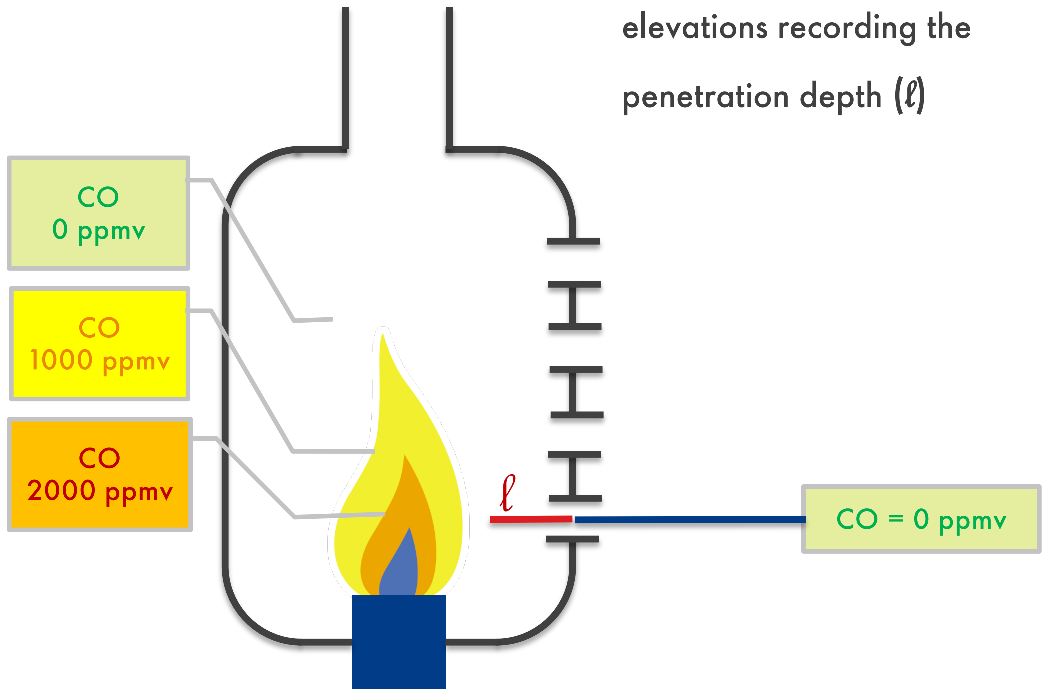
Flame shape should be uniform, centered on the burner axis and with length and width within specified requirements. Flame is the visually observable element of the combustion process. Flame dimensions should be recorded by visual observation and referenced off known test heater dimensions. The purchaser should specify desired dimensions as well as if there are minimum requirements. For example, both upper and lower limits for flame dimensions should be specified. If CO probing is required as a secondary method of verifying flame dimensions, the CO level should be determined ahead of time. It is generally considered that 99.99 % of the combustion reactions are complete at a CO isosurface of 2000 ppmvd. Also, the CO recorded should be averaged over a time period as CO fluctuates greatly as the measurement is being made in a turbulent environment.

The flame size (diameter or cross section and length), shape and intensity (color, luminosity and transparency) should be recorded for each test point. The test furnace dimensions (length, width and height) should be recorded.

# Flame definition by CO probing

Probe is outside the flame and CO reading is “0”, or at least less than 40ppmv

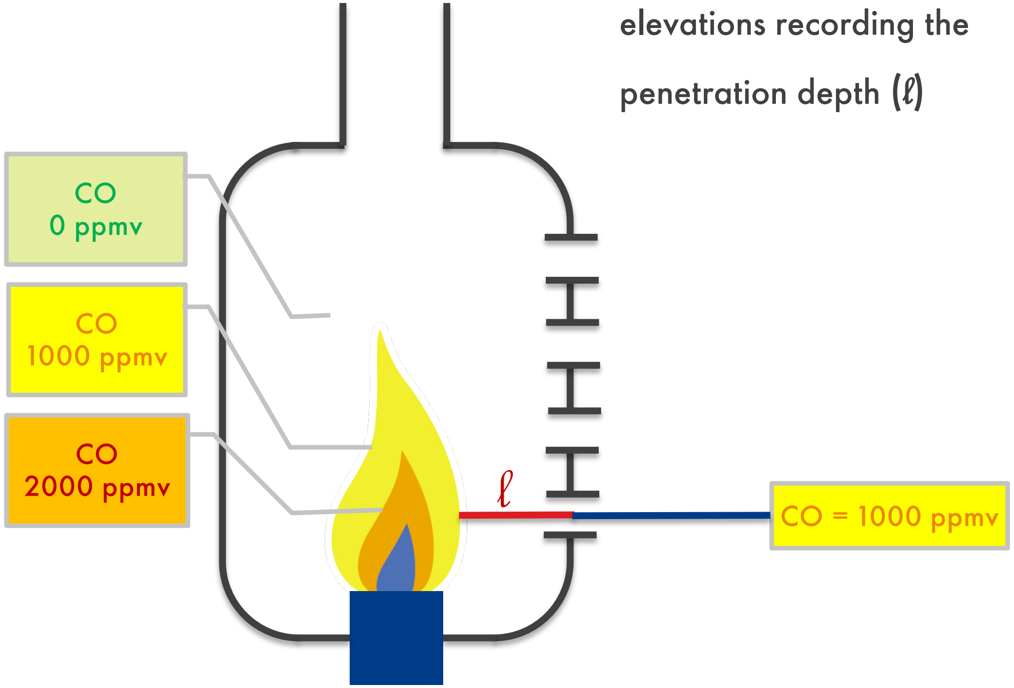
CO probing through the firebox at different elevations recording the penetration depth ($\ell$)



# Flame definition by CO probing

Probe enter the external layer of the flame and CO level raises up to 1000ppmv.

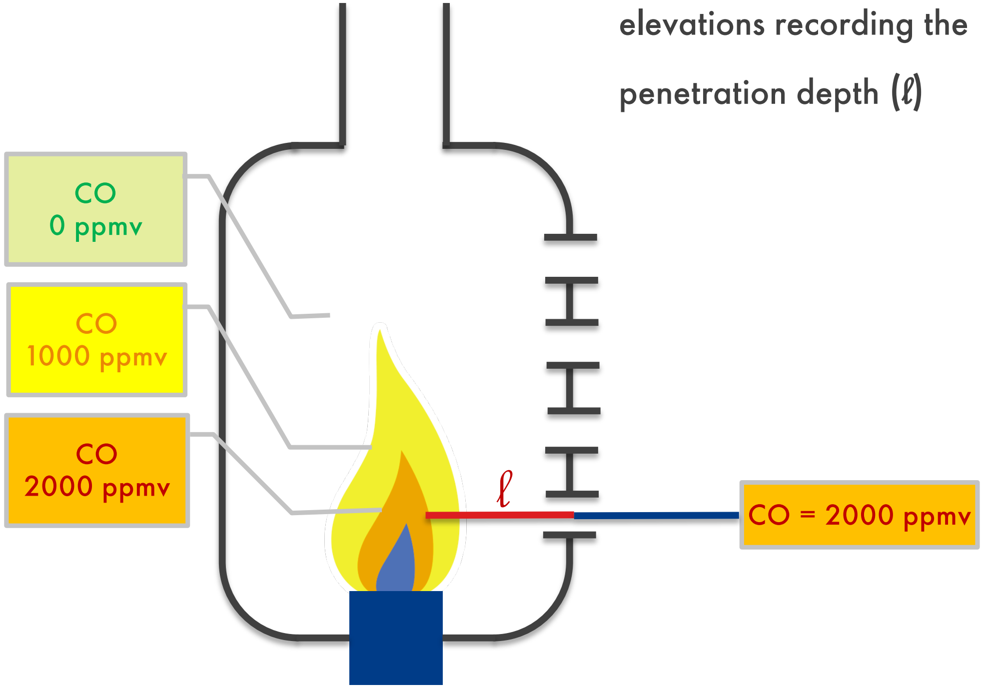
CO probing through the firebox at different elevations recording the penetration depth ($\ell$)



# Flame definition by CO probing

The probe penetrates deeper and finally capture the main flame. CO increases to 2000ppmv and this is the boundary level where we generally consider 99.99% of the combustion  reactions have completed.
2000ppmv threshold is a "suggested" value by API535 and there is full freedom for some user to specify any lower levels of CO threshold to give more margin to the design.

CO probing through the firebox at different elevations recording the penetration depth ($\ell$)



# H2 flames do not produce CO … so?

Industry and API already start discussing on how to define the H2 flame.

Possible solutions may be:

- O2 probing
- Heat Flux probing
- Validated CFD
- Etc ....

# Why H2 fuel is so special?

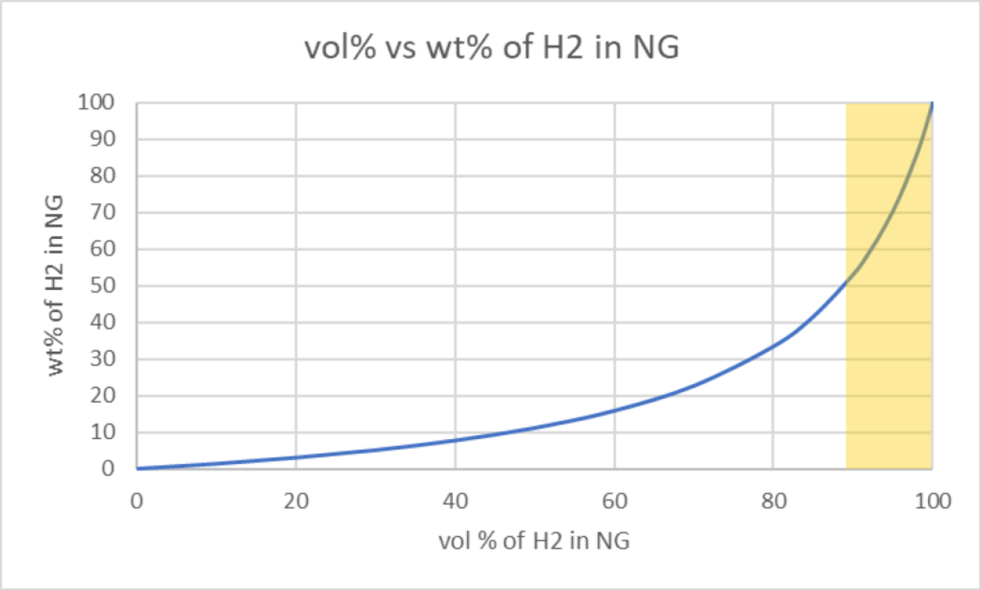
| | Natural Gas | Typical Refinery Gas | Hydrogen |
|---|---|---|---|
| Adiabatic Flame Temp * (°C) | 1700 | 1750 | 1885 |
| Laminar Flame Speed (cm/sec) | 40 | ~80 | 312 |
| volume based LHV (kcal/m3) | 7475 | 9967 | 2438 |

*AFT calculated with the same amount of excess air per each fuel

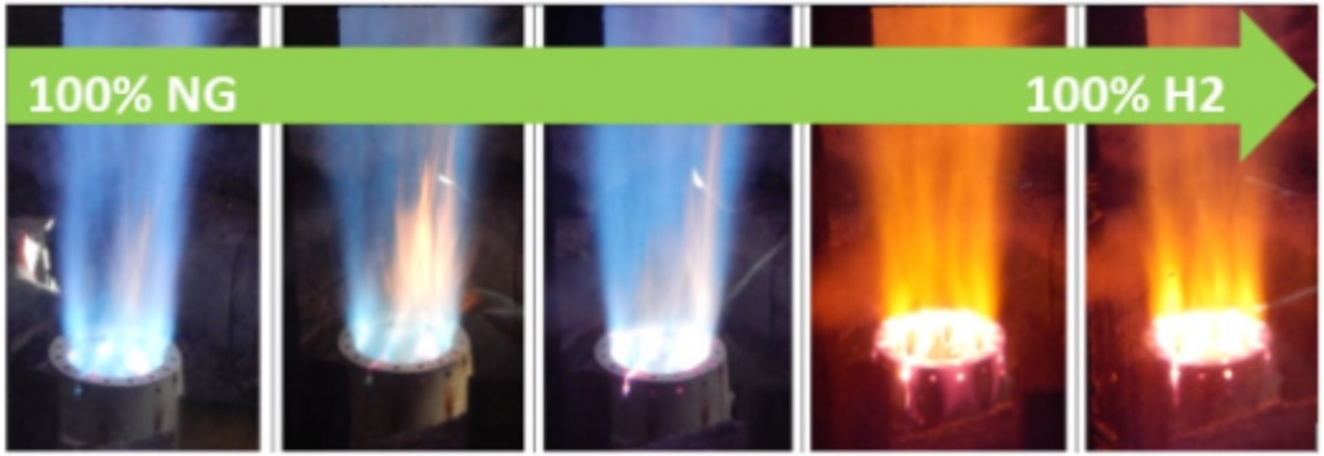
- H2 fuel pressure is higher than HC fuels at a given heat release
- SAR (Stochiometric Air Requirement) of H2 is lower than any other HC fuel
- Lower fluegas mass flowrate (partial duty swap between Convection and Radiant Sections)
- H2 flames are more compact (higher peak HF, higher NOx and HF profile moves down)
- Under certain conditions, H2 flames are less visible by human eyes

# What does H2 rich fuel mean?
# H2 concentration curve (H2/NG mixture)

- Non-linearity between vol% and wt%
- 80vol% = 33wt% → 90%vol = 50wt%
- Most of the challenges and differences between hydrocarbon firing and H2 firing start showing-up above 90vol% (50wt%)



# How H2 flame looks like

# NOx emission with H2 fuel

**Burners for Fired Heaters in General Refinery Services**

API RECOMMENDED PRACTICE 535
THIRD EDITION, MAY 2014

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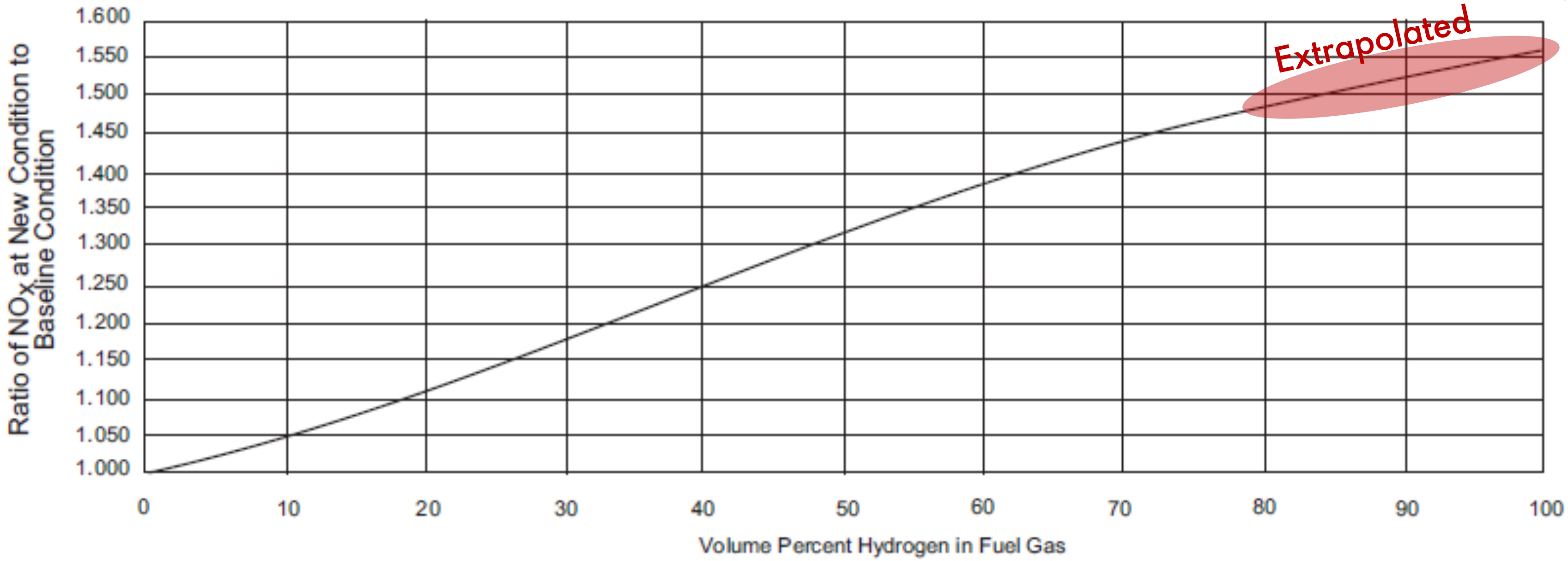


NOTE Figures are used for illustrative purposes and not to be used for verification or corrections. This figure is a generic curve and not applicable to individual low $NO_x$ burner designs.

**Figure 10—Effect of Hydrogen Content of Fuel Gas on $NO_x$ Emission**

# NOx emission with H2 fuel

**Burners for Fired Heaters in General Refinery Services**

API RECOMMENDED PRACTICE 535
THIRD EDITION, MAY 2014

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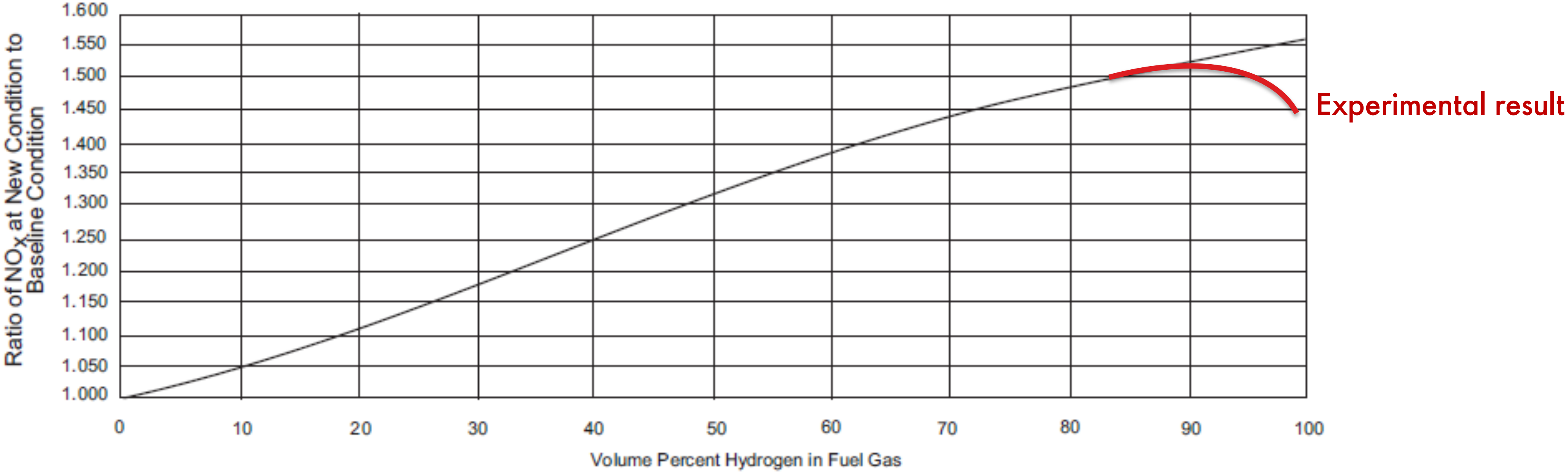
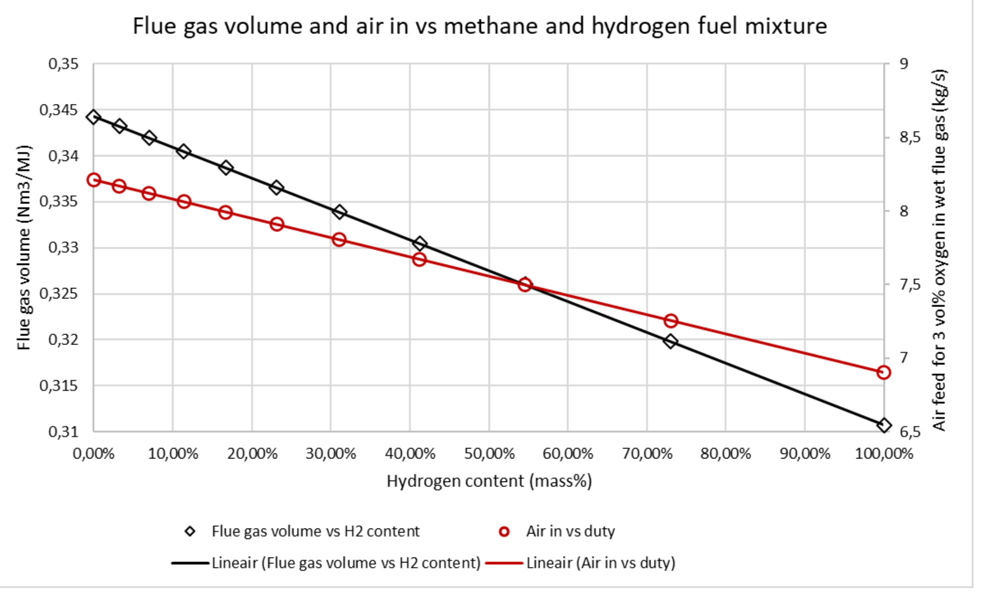



NOTE Figures are used for illustrative purposes and not to be used for verification or corrections. This figure is a generic curve and not applicable to individual low $NO_x$ burner designs.

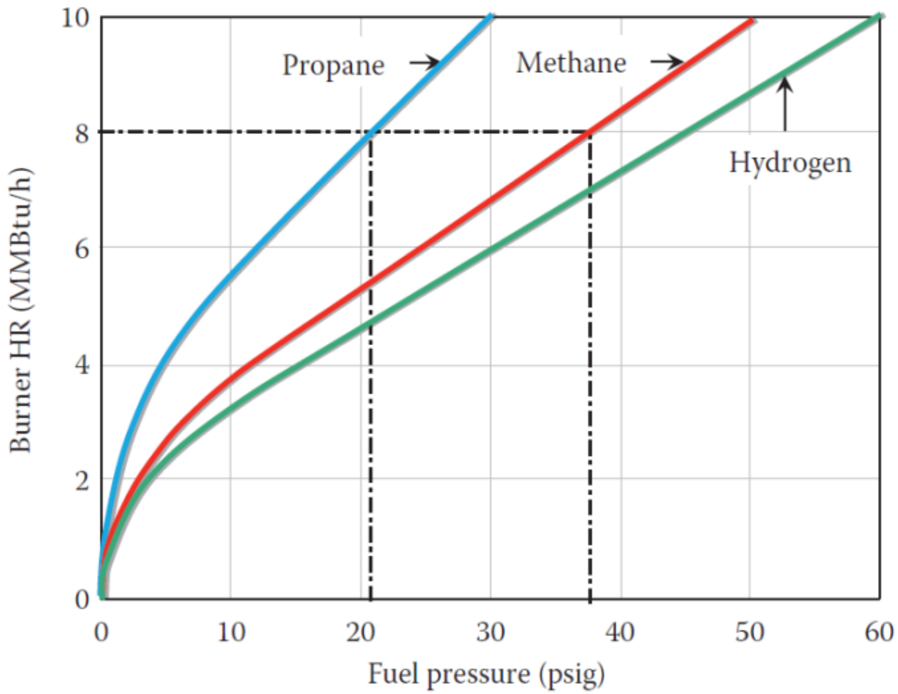
**Figure 10—Effect of Hydrogen Content of Fuel Gas on $NO_x$ Emission**

# How to properly compare (and report) NOx emissions for HC and H2 firing

| | Wet flue gas | | 'Dry' flue gas correcting for water produced by combustion at 3 vol% $O_2$ | |
|---|---|---|---|---|
| | $CH_4$ firing | $H_2$ firing | $CH_4$ firing | $H_2$ firing |
| $CO_2$ (vol%) | 8.1 | 0.0 | 8.4 | 0.0 |
| $O_2$ (vol%) | 2.9 | 2.8 | 3.0 | 3.0 |
| $N_2$ (vol%) | 71.6 | 66.6 | 74.1 | 70.5 |
| $H_2O$ (vol%) | 16.5 | 29.7 | 13.6 | 25.6 |
| Ar (vol%) | 0.9 | 0.8 | 0.9 | 0.8 |
| Flue gas volume ($Nm^3/MJ_{th}$) | 0.3422 | 0.3078 | 0.3307 | 0.2907 |
| NOx load (ton/y) | 10.0 | 10.0 | 10.0 | 10.0 |
| NOx conc. ($mg/Nm^3$) | 46.3 | 51.5 | 47.9 | 54.6 |
| NOx emission (gr/MWh) | 57.1 | 57.1 | 57.1 | 57.1 |

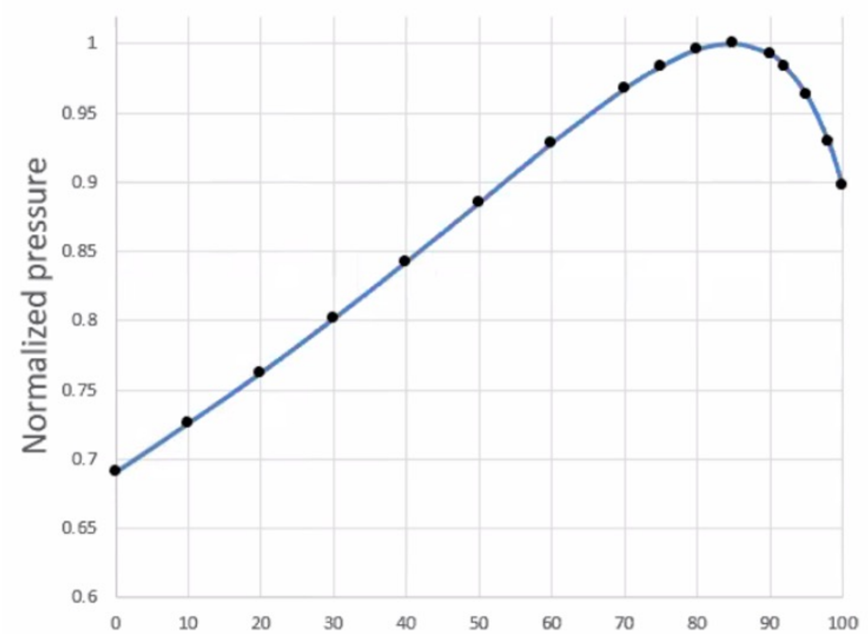


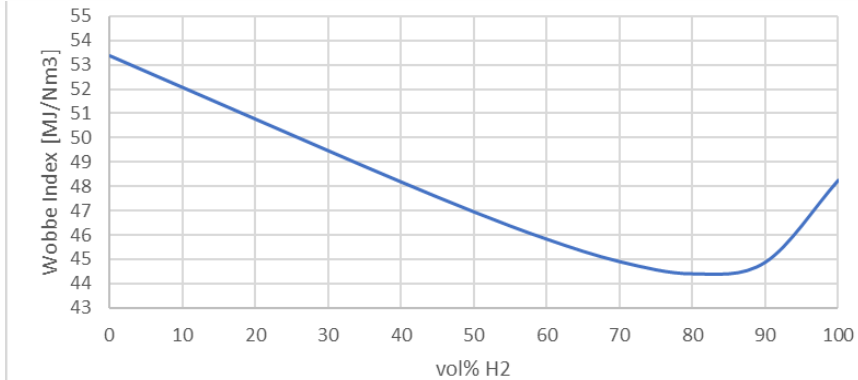
# Fuel transition and safeguarding




Ref: John Zink Hamworty Combustion Handbook

Effect of higher volume flow vs less resistance on overall Pressure drop



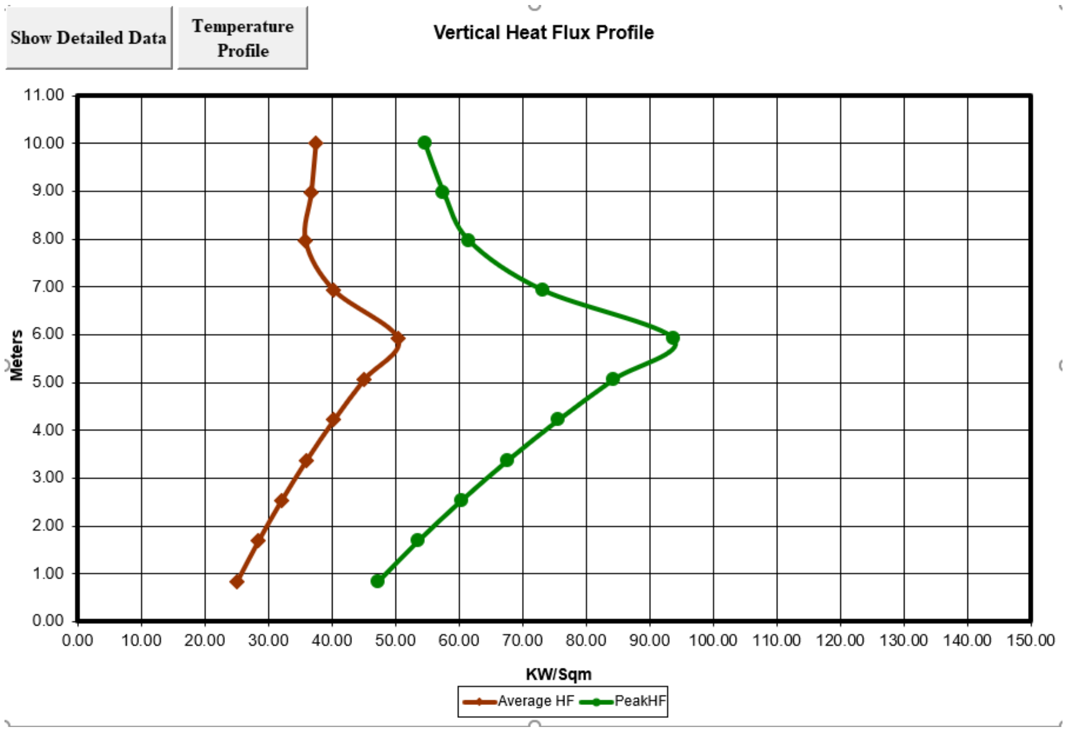
# Exercise 1

**Retrofit to Ultra Low NOx burner technology**

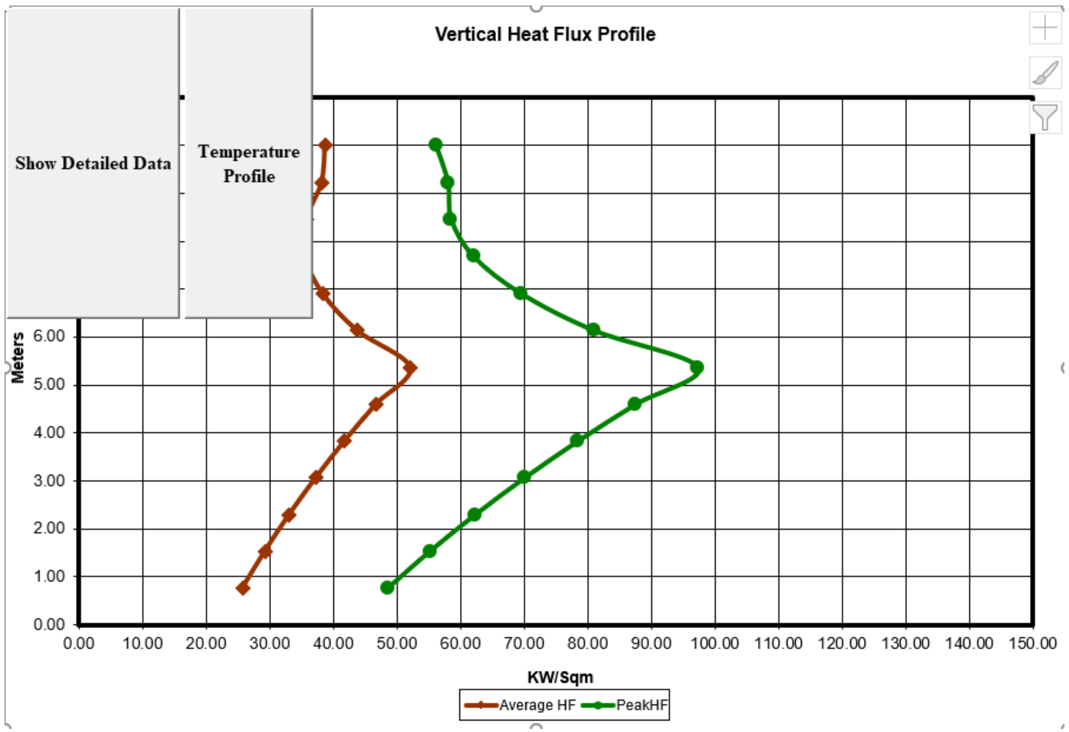
# Exercise 1: Expected (calculated) vertical Radiant Heat Flux Profile

It assumes same burner type, but we need ULNB to keep NOx low in H2 firing

FURDES model: RFG firing

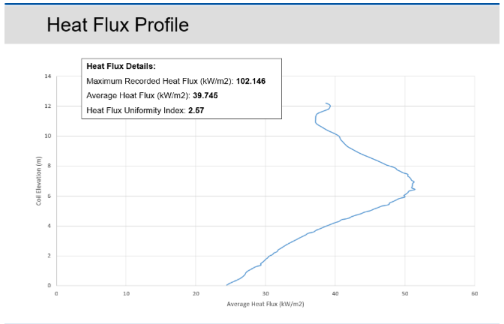


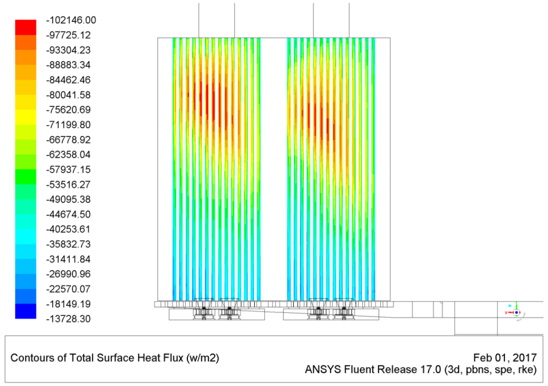

FURDES model: pure H2 firing

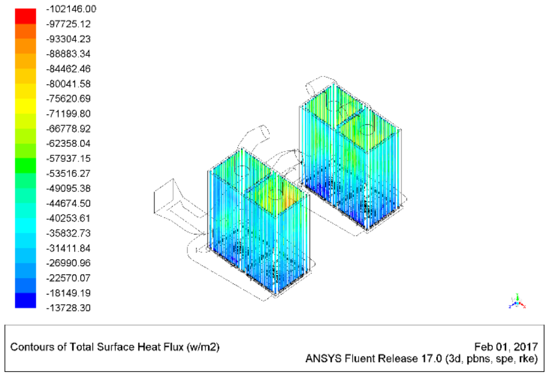


# Exercise 1: Burner retrofit to Ultra Low NOx technology

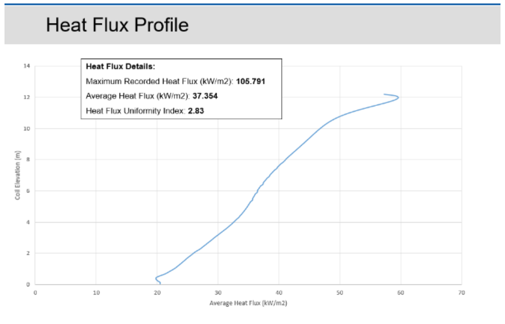
## Old burner (Conventional Burner)

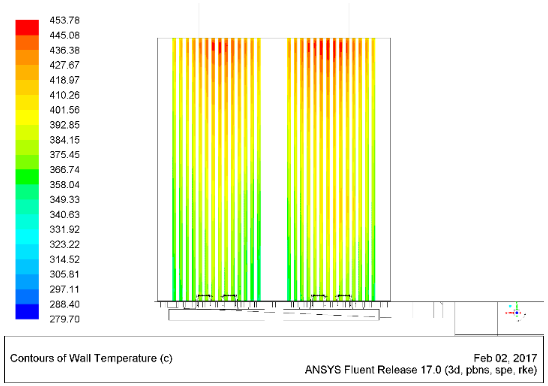


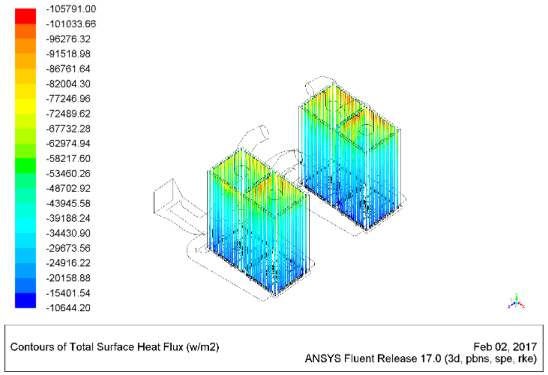



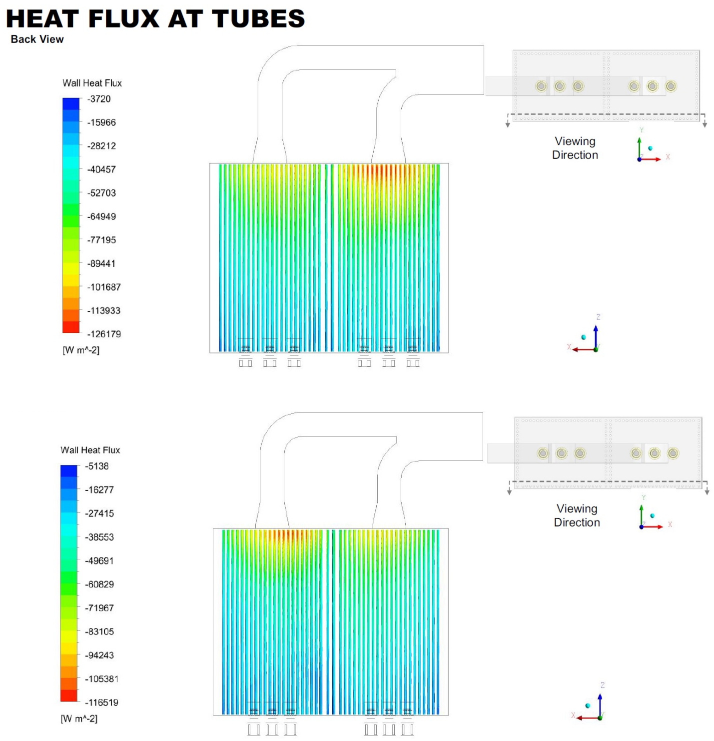

## New burner (Ultra Low NOx Burner)

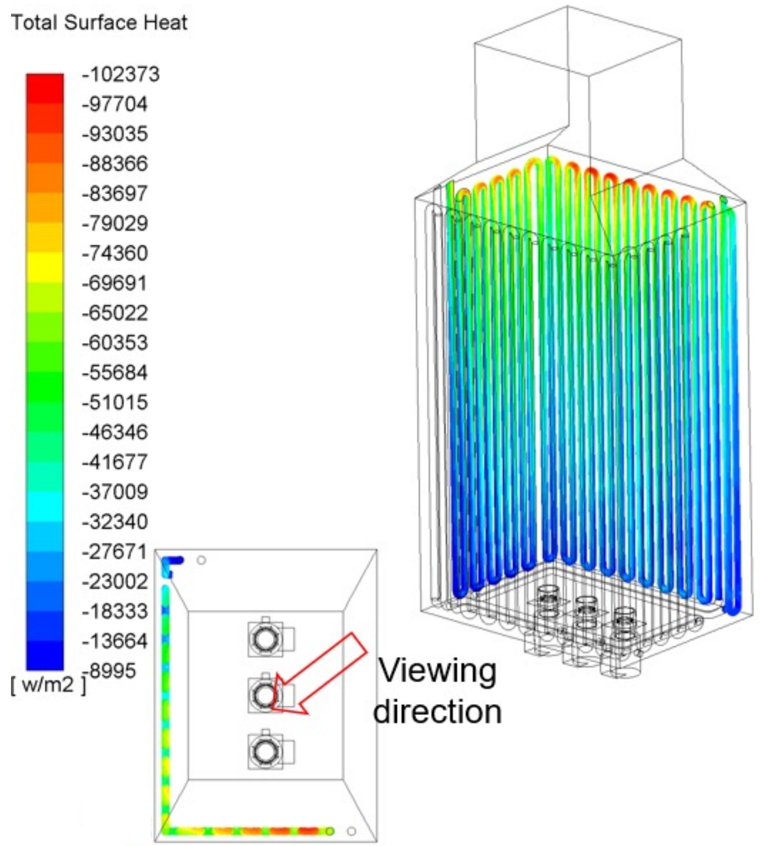


# Exercise 1: Burner retrofit to Ultra Low NOx technology

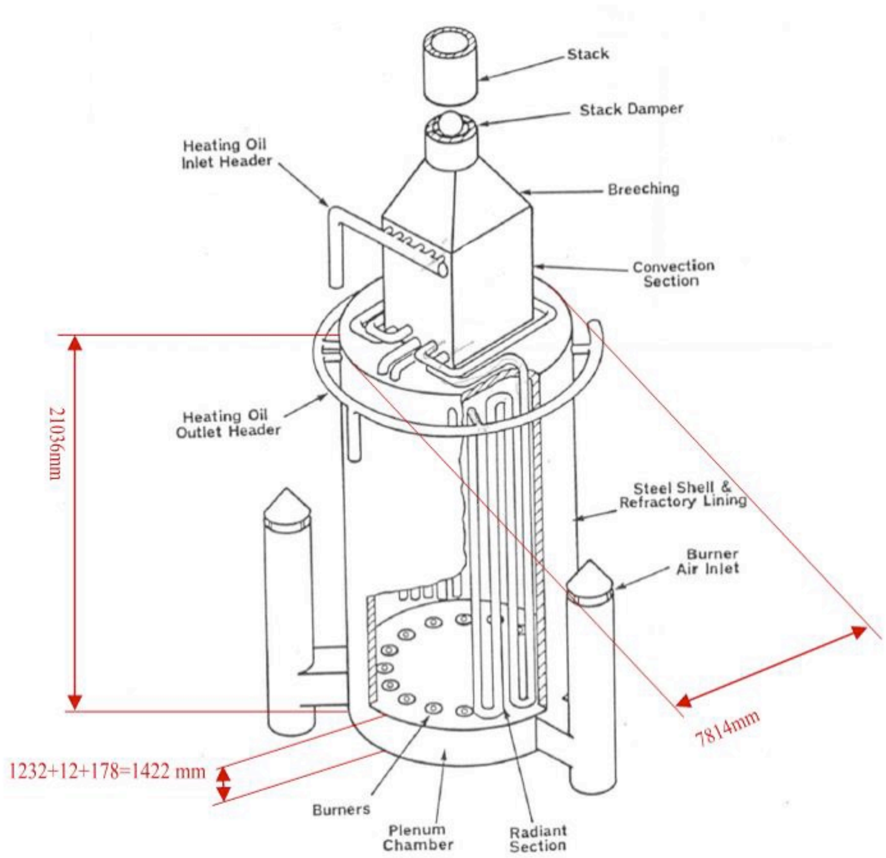


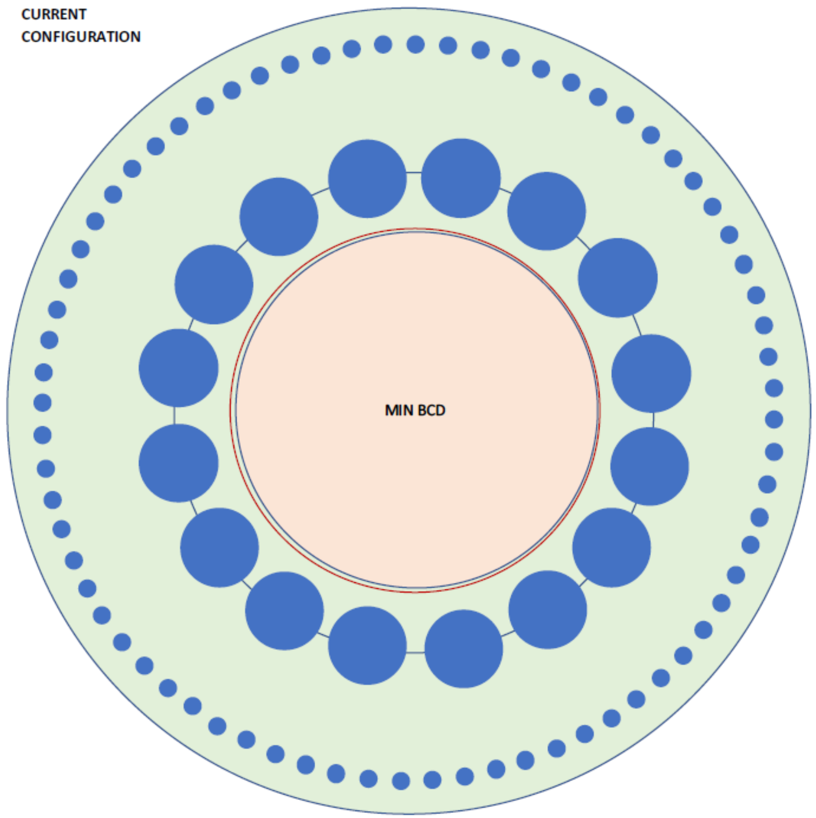



# Exercise 2

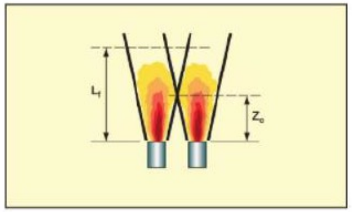
**Retrofit of a Natural draft VC heater to H2 firing**

# Exercise 2: Furnace and burner layout

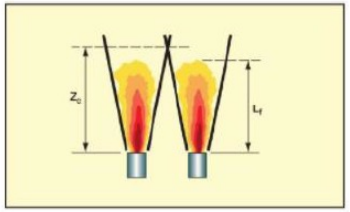


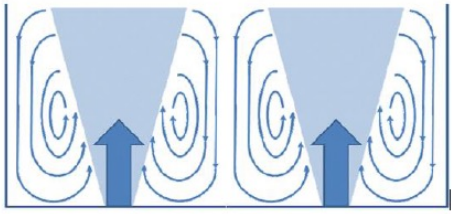
# Exercise 2: Flame interaction



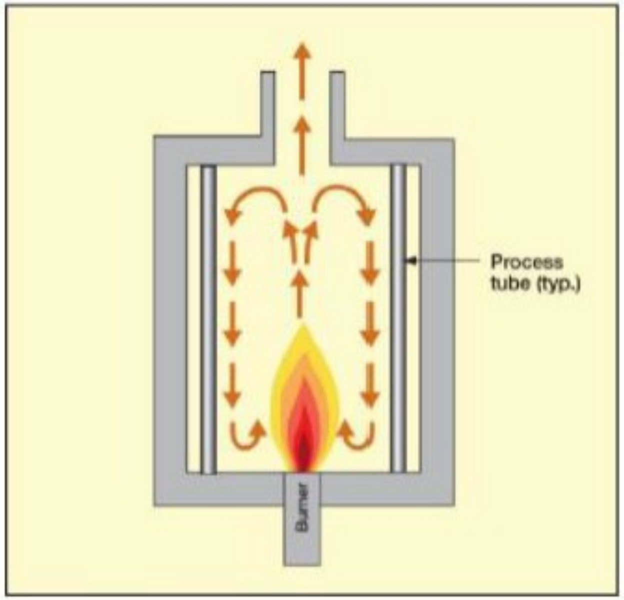
Burner spacing too small – flames interact merging on top.



Burners spacing sufficient only to avoid flame interaction but not to allow fluegas recirculation



Proper burner spacing for ULNB's. No flame interaction and sufficient space for fluegas recirculation

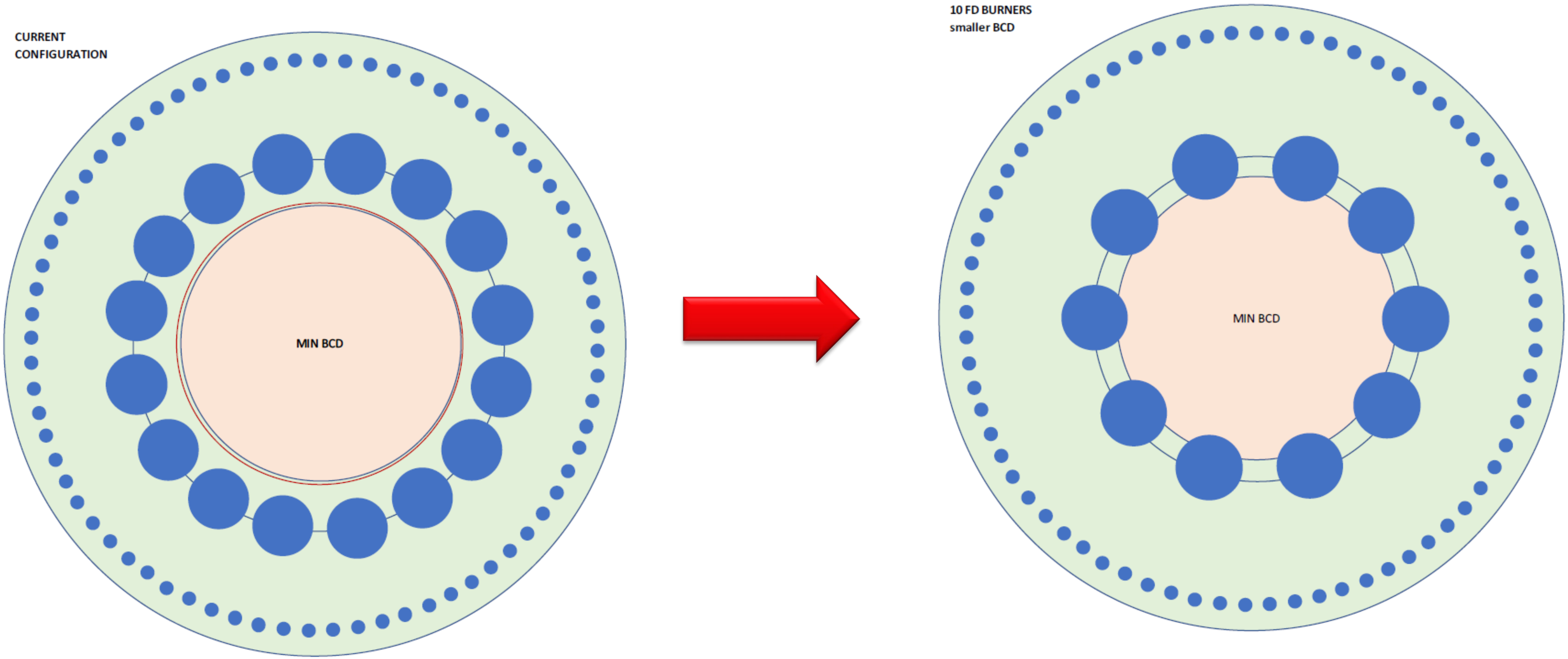


# Exercise 2: The importance of proper burner spacing

|  |  |
|---|---|
| Flames are too close, and the circle diameter is too small flames interact merging into a big single flame | Candle flames are properly spaced with right Circle diameter. The flames are slightly curved to the centre. |

Ref: John Zink Hamworty Combustion Handbook

# Exercise 2: New burner layout

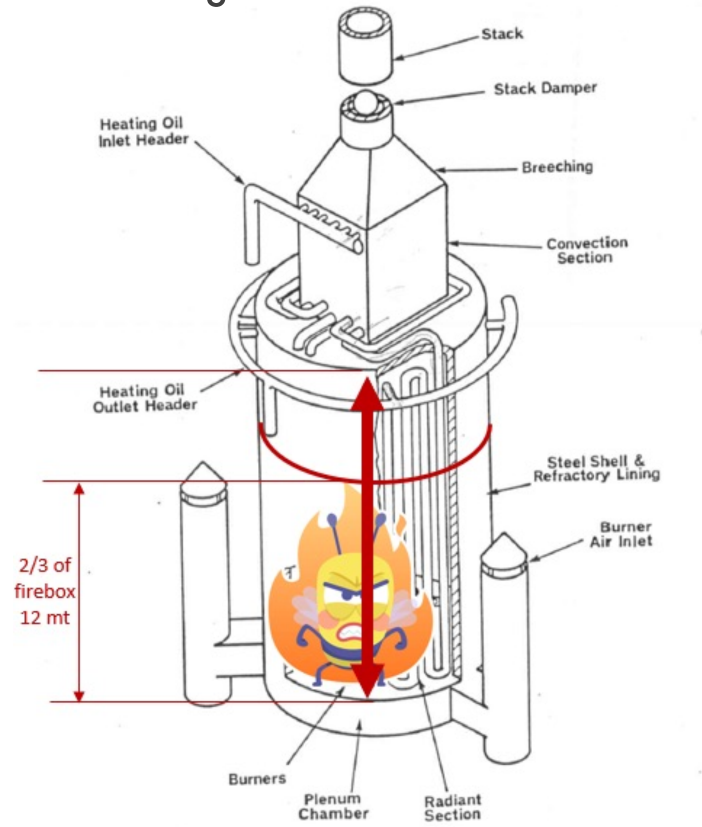


# Exercise 2: Flame length calculation

API560 requirement: flame length to not exceed $^2/_3$ of the firebox height

| | TOT firing duty | | 56 | MW | 191.1 | MMBTU/h |
|---|---|---|---|---|---|---|
| | Flame length [mt] | | | | Max firing duty | |
| | H2 firing | | HC firing | | MW per Burner | |
| #Burners | ND | FD | ND | FD | | |
| 16 | 8.19 | 5.04 | 9.10 | 5.60 | 3.50 | MW |
| 15 | 8.74 | 5.38 | 9.71 | 5.97 | 3.73 | MW |
| 14 | 9.36 | 5.76 | 10.40 | 6.40 | 4.00 | MW |
| 13 | 10.08 | 6.20 | 11.20 | 6.89 | 4.31 | MW |
| 12 | 10.92* | 6.72 | 12.13* | 7.47 | 4.67 | MW |
| 11 | 11.91* | 7.33 | 13.24* | 8.15 | 5.09 | MW |
| 10 | 13.10* | 8.06 | 14.56* | 8.96 | 5.60 | MW |
| 9 | 14.56* | 8.96 | 16.18* | 9.96 | 6.22 | MW |
| 8 | 16.38* | 10.08 | 18.20* | 11.20 | 7.00 | MW |
| 7 | 18.72* | 11.52 | 20.80* | 12.80 | 8.00 | MW |
| 6 | 21.84* | 13.44 | 24.27* | 14.93 | 9.33 | MW |

* firing duty not suitable for Natural Draft burner design (too high)



# Questions and Answers

Q&A