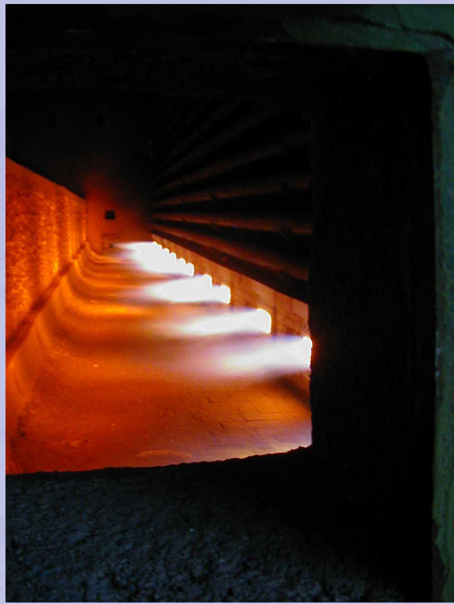

HAMWORTHY
COMBUSTION

Incorporating:

PEABODY ENGINEERING
AIROIL - FLAREGAS
CHENTRONICS

Operational and Design Issues Faced by Low NOx and Ultra Low NOx Burners

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AGENDA

- Statement of Intent
- The 3 W's???
  - Corporate Overview
  - Market Sectors
- What is Delayed Coking
- Burner Design – Historical Requirement
- Burner Design – Current Requirement
- Factors for Consideration in Burner Design
- Burner Design – Advantages of Staging Principals
- Burner Design – Future Requirements
- Burner Design – Next Generation Technology
- Necessities for Meeting End User Future Objectives
- Questions???

Statement of Intent

Hamworthy Combustion informs that the contents contained within this presentation, including all information and statements made, are not specific to any manufacturer type or model but are intended only as topics for discussion with the intent to simply raise the criticality of certain information and data necessary to review the correct design, operation and function of Low NOx and Ultra Low NOx burners and how if not correctly interpreted this lack of clarity in information can lead to incorrectly designed equipment which in turn could lead to a loss in furnace efficiency and overall production of the furnace itself.

Hamworthy Combustion
Global Solutions, Local Delivery

WHO ARE HAMWORTHY COMBUSTION?

WHAT COMBUSTION EQUIPMENTS DO
WE SUPPLY??

WHICH MARKET SECTORS DO WE SUPPORT???

THE 3 W's ???

CORPORATE INFORMATION.

•History **Established since 1911**

•No. of Employees **700 + worldwide**

•Annual Turnover **US$160 million**

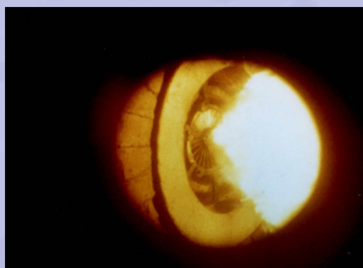
•Offices

- **Major European Economies**
- **Japan** **Korea**
- **India** **Mexico**
- **United States** **Brazil**
- **China** **Singapore**
- **Poland** **Dubai**

Fully comprehensive Advanced Technology Centre incorporating 14 test furnaces

MARKET SECTORS – CUSTOMER CENTRIC

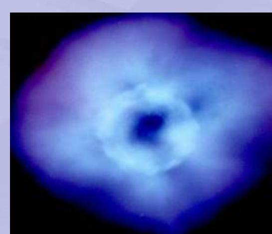
Power



Marine

Thermal Oxidation Systems & Flares

Process



Industrial

Sales → Contracts → Commissioning → Service → Spares

- Marine
- Power
- TOS & Flares
- Process
- Industrial

Dedicated teams of c 100 people focussed on each sector: specialists, 100% full time

We are a true customer solutions provider in the highly specialised markets we serve

What is Delayed Coking?

- I am still learning and hope to continue to learn, but!
- A process which incorporates a fired heater which is used to obtain thermal cracking temperatures of 905 – 940^{0}F having horizontal tubes within which feed stock is processed at short residence times to ensure "delayed coking" occurs downstream of the heater in coking drums.
- A fired heater installation having up to 1,000 burners installed of low firing capacity.
- A large capital investment requiring optimum continual performance from all equipment installed to ensure maximum furnace efficiency is achieved with minimum maintenance requirements.

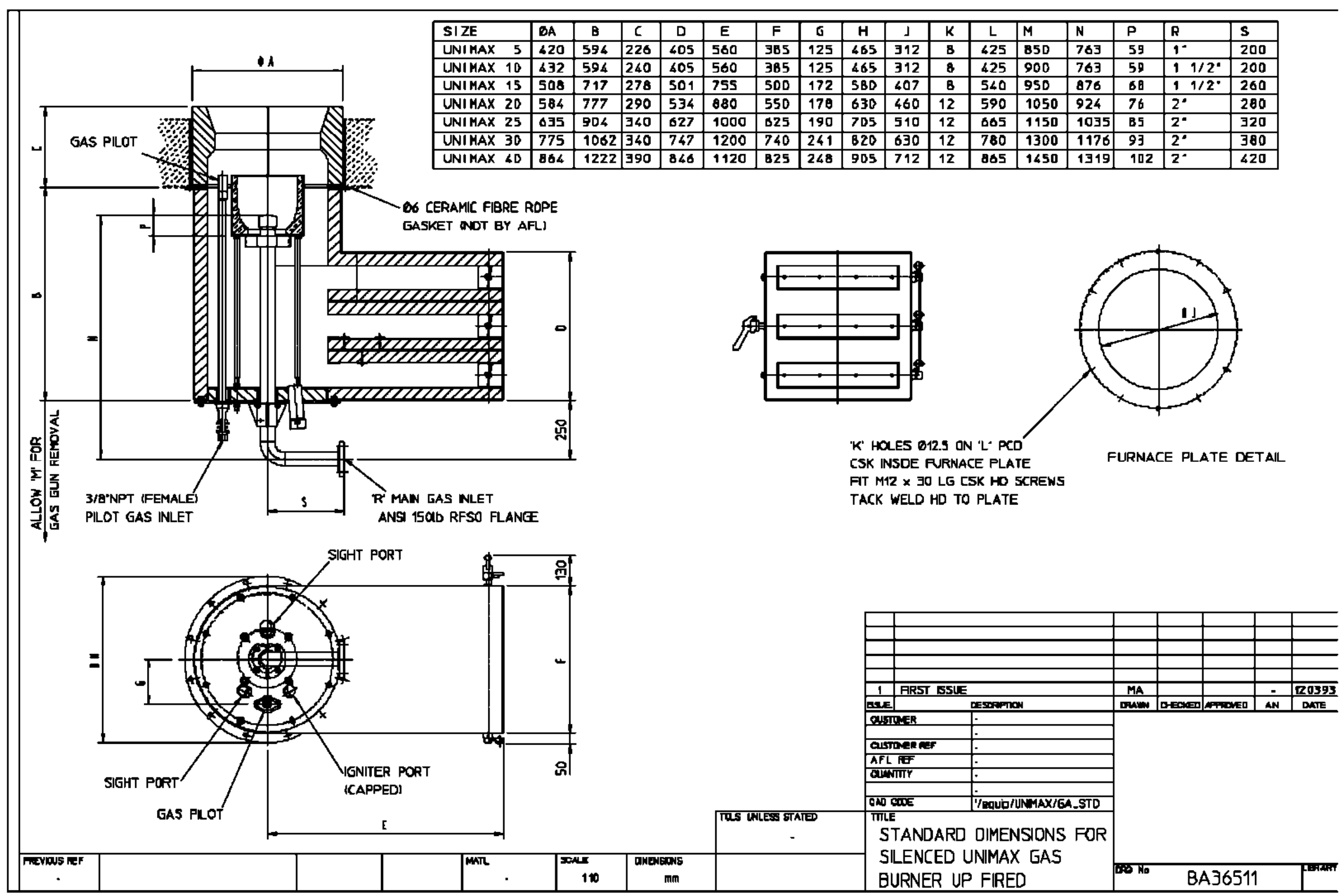
Delayed Coking – Burner Design Consideration Historical Requirements....

- Burners firing gas & oil
- High excess air levels – oil firing 25-30% / gas firing 20-25%
- CO emissions of < 200 vppm
- Nox emissions of < 150 vppm for gas firing / < 350 vppm for oil firing
- UHC guarantees not required
- No defined noise guarantee
- Turndown limits of 3:1 oil firing / ≥ 5:1 gas firing
- Round Flame central burners / flat flame side burners

RESULTS????

Conventional burner design with good stability, low risk, low maintenance but high emissions and in some cases low furnace efficiency!

Delayed Coking – Historical Burner Design....



SIZE	ØA	B	C	D	E	F	G	H	J	K	L	M	N	P	R	S
UNIMAX 5	420	594	226	405	560	385	125	465	312	8	425	850	763	59	1"	200
UNIMAX 10	432	594	240	405	560	385	125	465	312	8	425	900	763	59	1 1/2"	200
UNIMAX 15	508	717	278	501	755	500	172	580	407	8	540	950	876	68	1 1/2"	260
UNIMAX 20	584	777	290	534	880	550	178	630	460	12	590	1050	924	76	2"	280
UNIMAX 25	635	904	340	627	1000	625	190	705	510	12	665	1150	1035	85	2"	320
UNIMAX 30	775	1062	340	747	1200	740	241	820	630	12	780	1300	1176	93	2"	380
UNIMAX 40	864	1222	390	846	1120	825	248	905	712	12	865	1450	1319	102	2"	420

Delayed Coking – Burner Design Considerations Current Requirements.....

- Burners predominantly firing gas (and oil depending on country)
- Low excess air levels – 10% (oil 20-25%)
- CO emissions of < 25 - 50 vppm
- Nox emissions of < 25 - 35 vppm for gas firing (150 – 200 vppm oil firing)
- UHC guarantees < 10 ppm
- Noise levels < 80-85 dB 'A'
- Turndown limits of 5:1
- Round flame central burners / flat flame side burners
- Ability to fire various range of fuel gas cases from high H2 to heavies and double bonded characteristics
- Increasing tendency for burners having lower firing capacity but higher number in quantities

Delayed Coking – Burner Design Considerations Current Requirements....Cont'd

RESULTS????

- Detailed low NOx or ultra low NOx burner design requiring careful design considerations in order to achieve good stability, low maintenance requirements and tighter operational control
- The increasing need to review NOx reduction techniques vs burner operating envelope and flame configuration/shape.
- The increasing need to review fuel gas compositions and operating temperatures
- The need for closer integration of end user, EPC, heater contractor and burner vendor
- The need to ensure all correct design data and information is fully received and considered in the final burner design parameters
- The need for open honesty about what can and can not be achieved in order to avoid long term maintenance and operational issues.

Low NOx and Ultra Low NOx Burners – Factors for Consideration

- **Receiving the correct and complete design data requirements, incl...**
  - Altitude above sea level clearly stated.
  - Units of Liberation clearly stated.
  - Maximum pressure drop across burner correctly stated.
  - Design duty vs normal duty vs minimum duty fully reviewed
  - Fuel compositions and conditions clearly stated.
  - Emissions requirements stated with no additional safety factor added

Low NOx and Ultra Low NOx Burners – Factors for Consideration

PURCHASER / OWNER: CLIENTS NAME	ITEM No.: FURNACE #
SERVICE:	LOCATION: SITE

GENERAL DATA

			REV
1	TYPE OF HEATER		
2	ALTITUDE ABOVE SEA LEVEL, ft		
3	AIR SUPPLY AMBIENT / PREHEATED AIR / TEG		
4	TEMPERATURE, °F (MIN / MAX / DESIGN)		
5	RELATIVE HUMIDITY, %		
6	DRAFT TYPE: FORCED / NATURAL / INDUCED		
7	DRAFT AVAILABLE: ACROSS BURNER, . in. H_2O		
8	ACROSS PLENUM, . in. H_2O		
9	REQUIRED TURNDOWN		
10	BURNER WALL SETTING THICKNESS, in.		
11	HEATER CASING THICKNESS, in.		
12	FIREBOX HEIGHT, ft		
13	TUBE CIRCLE DIAMETER, in.		

BURNER DATA

14	MANUFACTURER		
15	TYPE OF BURNER		
16	MODEL / SIZE		
17	DIRECTION OF FIRING		
18	LOCATION (ROOF / FLOOR / SIDEWALL)		
19	NUMBER REQUIRED		
20	MINIMUM DISTANCE BURNER CENTRELINE, ft		
21	TO TUBE CENTRELINE (HORIZONTAL / VERTICAL)		
22	TO ADJACENT BURNER CENTRELINE (HORIZ / VERT)		
23	TO UNSHIELDED REFRACTORY (HORIZ / VERT)		
24	BURNER CIRCLE DIAMETER,.in.		
25	PILOTS:		
26	NUMBER REQUIRED		
27	TYPE		
28	IGNITION METHOD		
29	FUEL		
30	FUEL PRESSURE, Psig		
31	CAPACITY, Btu/H		

OPERATING DATA

32	FUEL		
33	HEAT RELEASE PER BURNER, MMkcal/hr MMBtu/hr MW (LHV)		
34	DESIGN		
35	NORMAL		
36	MINIMUM		
37	EXCESS AIR @ DESIGN HEAT RELEASE, %		
38	AIR TEMPERATURE, °F		
39	DRAFT (AIR PRESSURE) LOSS in. H_2O		
40	DESIGN		
41	NORMAL		
42	MINIMUM		
43	FUEL PRESSURE REQUIRED @ BURNER, Psig		
44	FLAME LENGTH @ DESIGN HEAT RELEASE, ft		
45	FLAME SHAPE (ROUND, FLAT, ETC)		
46	ATOMISING MEDIUM / OIL RATIO, lb/ lb		

BURNER DATA SHEET API STANDARD 560	PROJECT No.	DOCUMENT No.	SHEET	REV
	SALES	TBA	1 OF 3	

GAS FUEL CHARACTERISTICS

1	FUEL TYPE		
2	HEATING VALUE (LHV),		
3	SPECIFY GRAVITY (AIR = 1.0)		
4	MOLECULAR WEIGHT		
5	FUEL TEMPERATURE @ BURNER, °F		
6	FUEL PRESSURE AVAILABLE @ BURNER, Psig		
7	FUEL GAS COMPOSITION, MOLE %		
8		CH4	
9		C2H6	
10		C3H8	
11		C4H10	
12		C5H12	
13		H2	
14		N2	
15		TOTAL	

LIQUID FUEL CHARACTERISTICS

16	FUEL TYPE		
17	HEATING VALUE (LHV),		
18	SPECIFIC GRAVITY / DEGREE API		
19	H/C RATIO (BY WEIGHT)		
20	VISCOSITY @	°F (CST)	
21	VISCOSITY @	°F (CST)	
22	VANADIUM,	PPM	
23	SODIUM,	PPM	
24	POTASSIUM,	PPM	
25	NICKEL,	PPM	
26	FIXED NITROGEN	PPM	
27	SULFUR,	% WT	
28	ASH	% WT	
29	LIQUIDS	ASTM INITIAL BOILING POINT, °F	
30		ASTM END POINT, °F	
31	FUEL TEMPERATURE @ BURNER, °F		
32	FUEL PRESSURE REQUIRED @ BURNER, Psig		
33	ATOMISING MEDIUM:	AIR / STEAM / MECHANICAL	
34		TEMPERATURE, °F	
35		PRESSURE, Psig	

MISCELLANEOUS

36	BURNER PLENUM:	COMMON / INTEGRAL	
37		MATERIAL	
38		PLATE THICKNESS, in	
39		INTERNAL INSULATION	
40	AIR INLET CONTROL:	DAMPER OR REGISTERS	
41		MODE OF OPERATION	
42		LEAKAGE, %	
43	BURNER TILE:	COMPOSITION	
44		MAXIMUM SERVICE TEMP, °F	
45	NOISE SPECIFICATION		
46	ATTENUATION METHOD		
47	PAINTING REQUIREMENTS		
48	IGNITION PORT:	SIZE / NO	
49	SIGHT PORT:	SIZE / NO	
50	FLAME DETECTION:	TYPE	
51		NUMBER / LOCATION	
52		CONNECTION SIZE	
53	SAFETY INTERLOCK SYSTEM FOR ATOMISING MEDIUM & OIL		
54	PERFORMANCE TEST REQUIRED (YES OR NO)		

BURNER DATA SHEET API STANDARD 560	PROJECT No.	DOCUMENT No.	SHEET	REV
	SALES	TBA	2 OF 3	

EMISSION REQUIREMENTS

				REV
1	FIREBOX TEMPERATURE	°F		
2	NOX	* Vppm		
3	CO	* Vppm		
4	UHC	* Vppm		
5	PARTICULATE	*		
6	SOX	*		
7				
8	* CORRECTED TO 3% O_2 (DRY BASIS @ DESIGN HEAT RELEASE)			
9	NOTES:			
10				
11	1) SOX EMISSIONS ARE A DIRECT RESULT OF THE FUEL BOUND SULPHUR AND CANNOT BE CONTROLLED BY THE			
12	COMBUSTION PROCESS, FOR THIS REASON WE DO NOT OFFER AS A GUARANTEE POINT.			
13				
14	2) THE ABOVE EMISSION DATA IS BASED ON THE FOLLOWING CRITERIA :-			
15	EXCESS AIR OF			
16	AIR TEMPERATURE OF			
17	H^2 IN FUEL GAS OF			
18	N^2 IN FUEL OIL OF			
19	FURNACE TEMPERATURE OF			
20	OPERATING RANGE OF NORMAL TO MAXIMUM LIBERATION.			
21				
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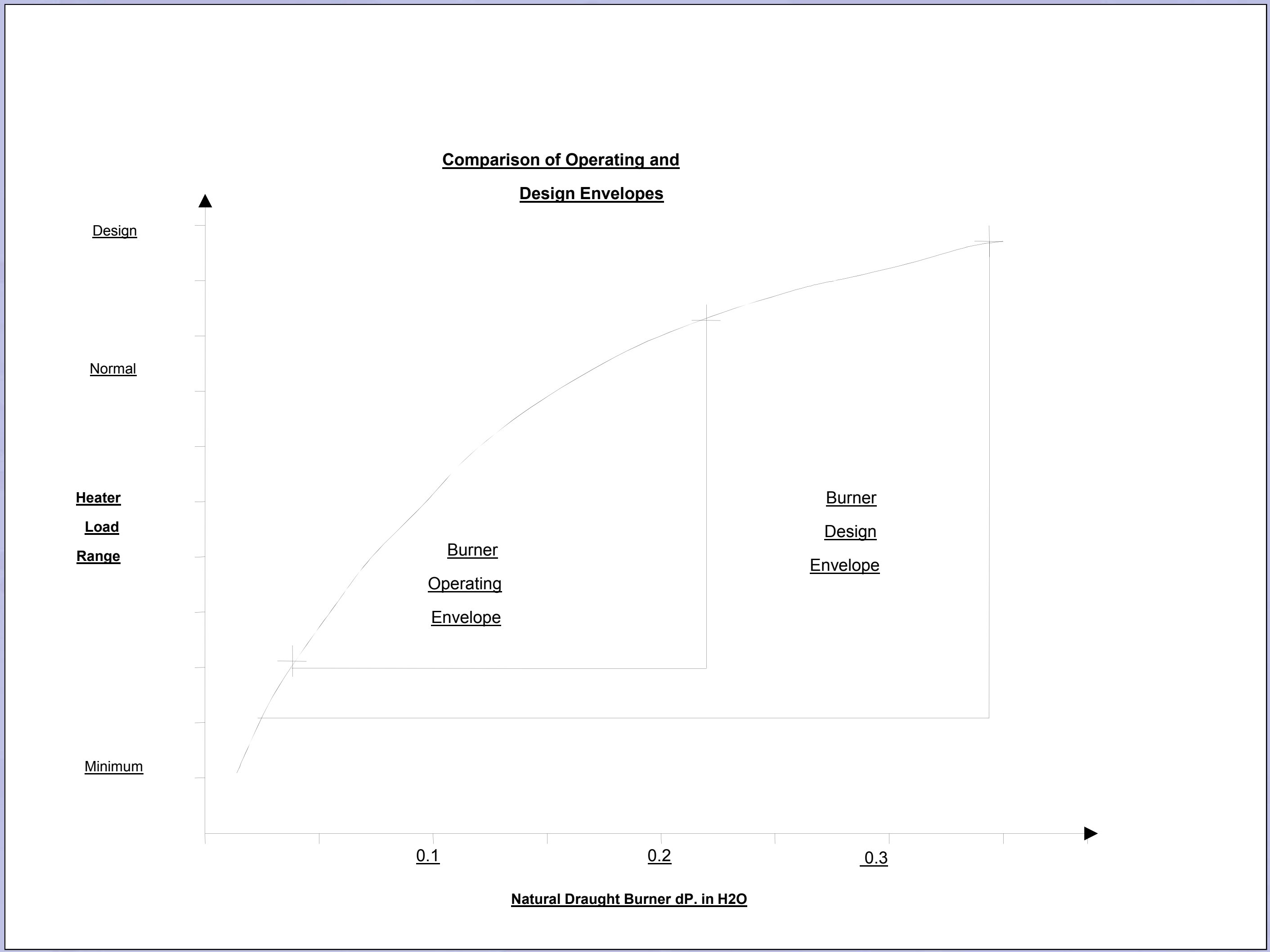
BURNER DATA SHEET API STANDARD 560	PROJECT No.	DOCUMENT No.	SHEET	REV
	SALES	TBA	3 OF 3	

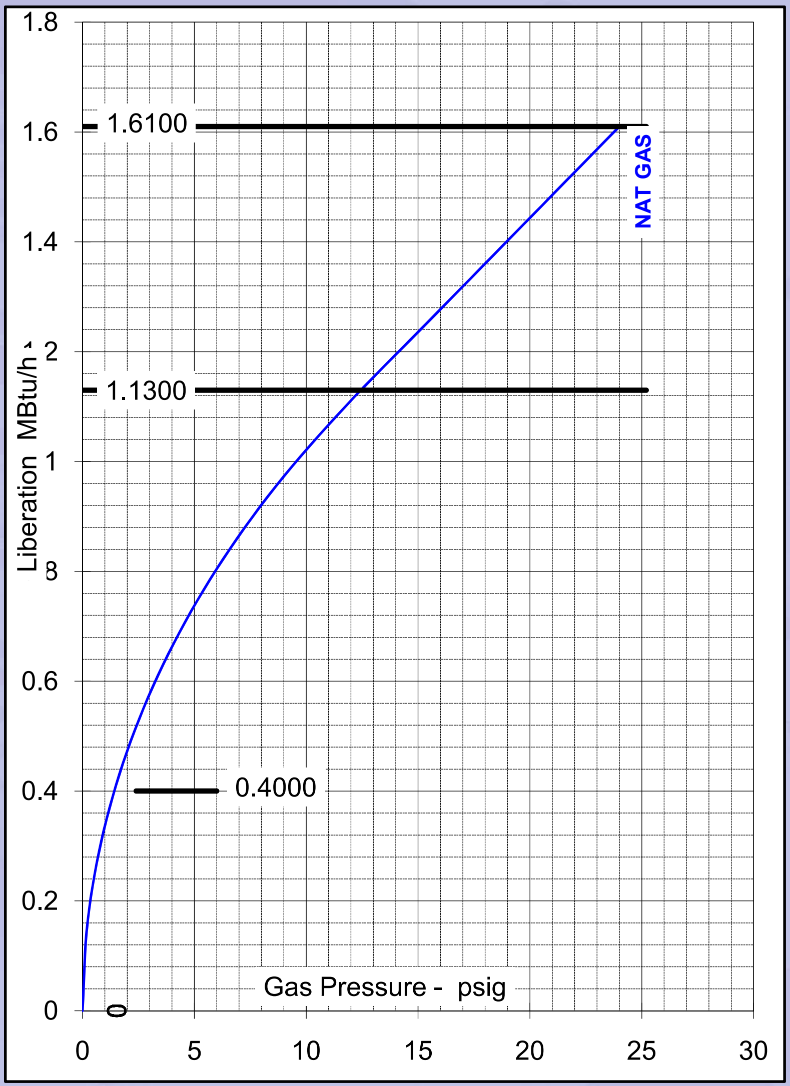
Low NOx and Ultra Low NOx Burners – Factors for Consideration



Low NOx and Ultra Low NOx Burners – Factors for Consideration

- **Reviewing completely the fuel gas compositions, temperatures and operating pressures**
  - Single fuel gas firing
  - Requirement to fire high H2 gases to LPG, Butanes, etc...
  - Climatic / ambient temperatures and effect on fuel gas conditions.
  - Increased tendency for coke formation through variation of fuels.
  - Possibility of increased maintenance as a result of burner design choice vs fuel gas composition.

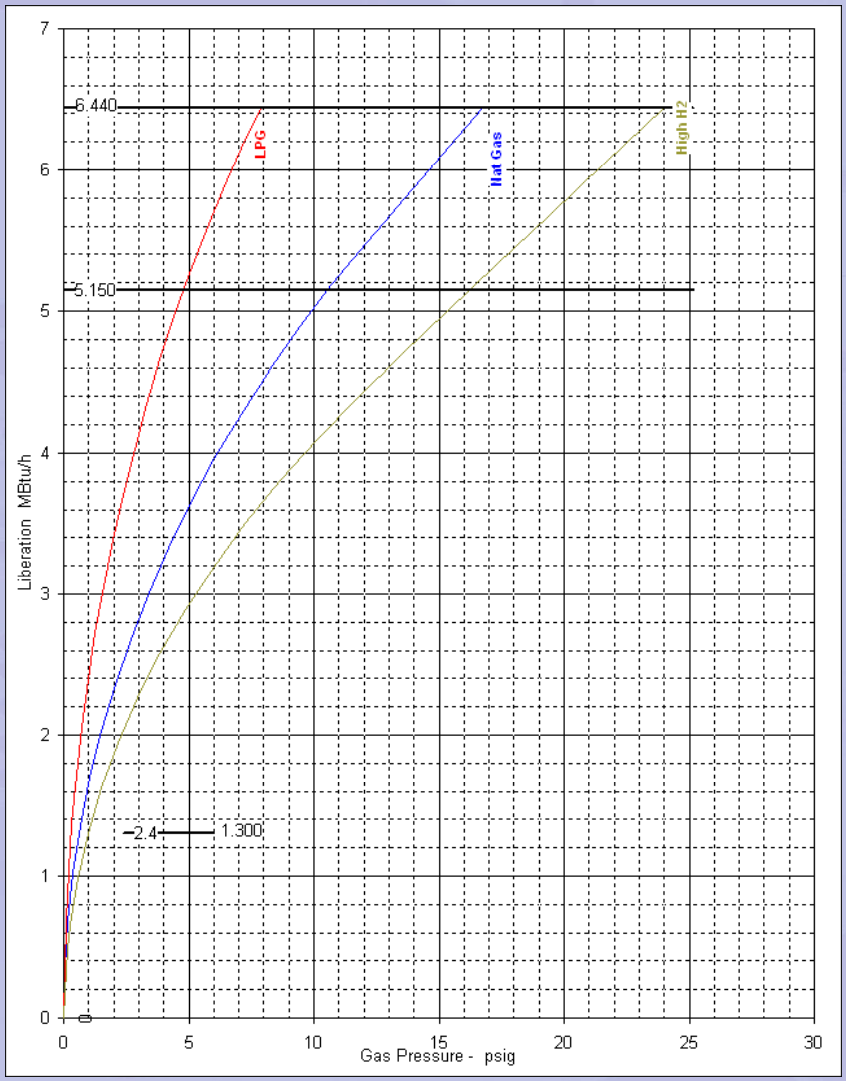
Low NOx and Ultra Low NOx Burners – Factors for Consideration



Single gas only =

- good pressure
- good velocity
- good fuel to air mixing
- good combustion
- low maintenance

Low NOx and Ultra Low NOx Burners – Factors for Consideration



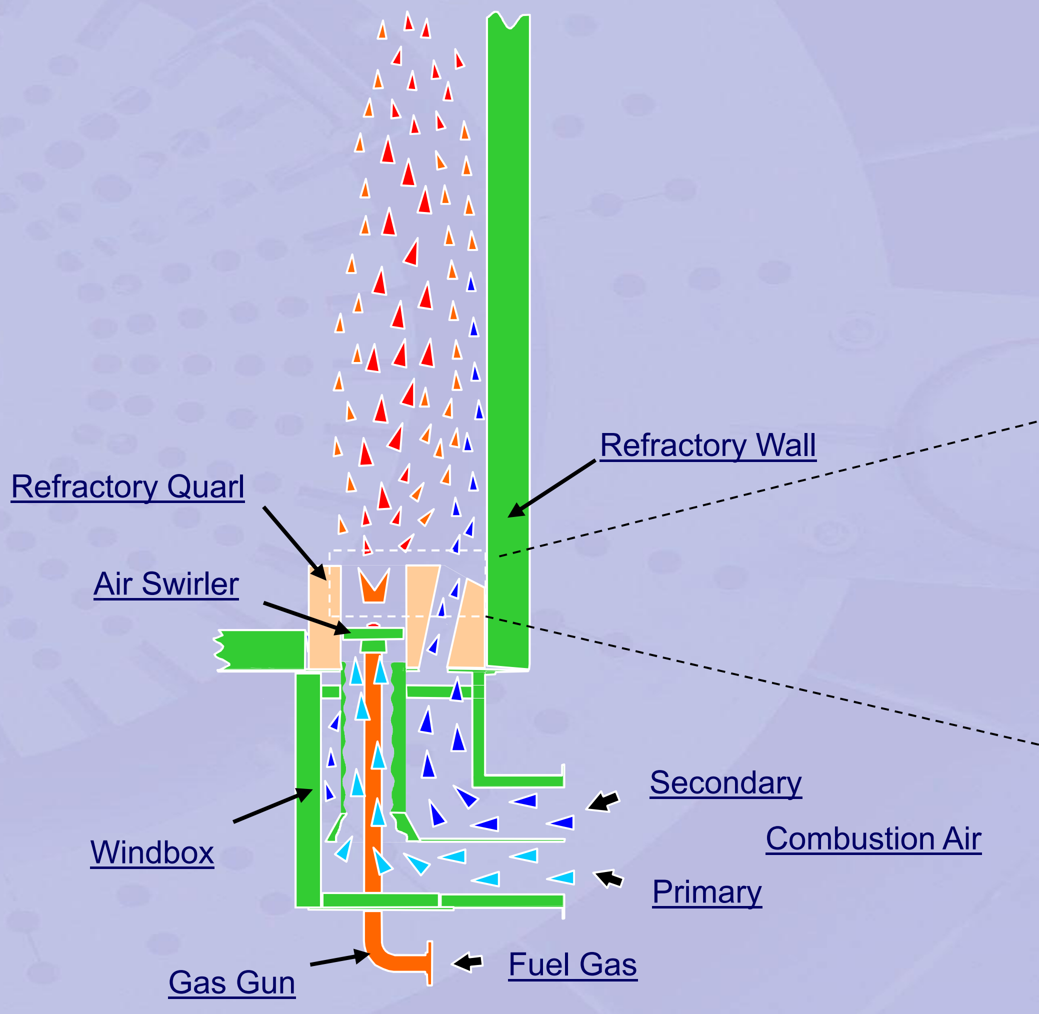
Multi gas cases =

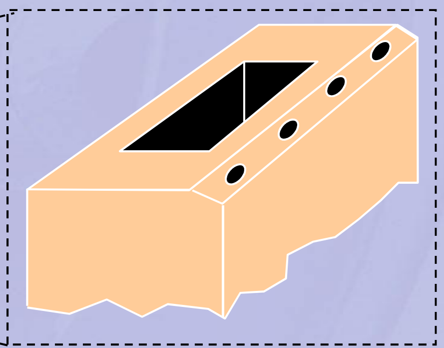
- lower pressure for high MW gases
- lower velocity for higher MW gases
- Poorer fuel to air mixing for higher MW gases
- higher design review to achieve good combustion
- possible increase in maintenance

Low NOx and Ultra Low NOx Burners – Factors for Consideration

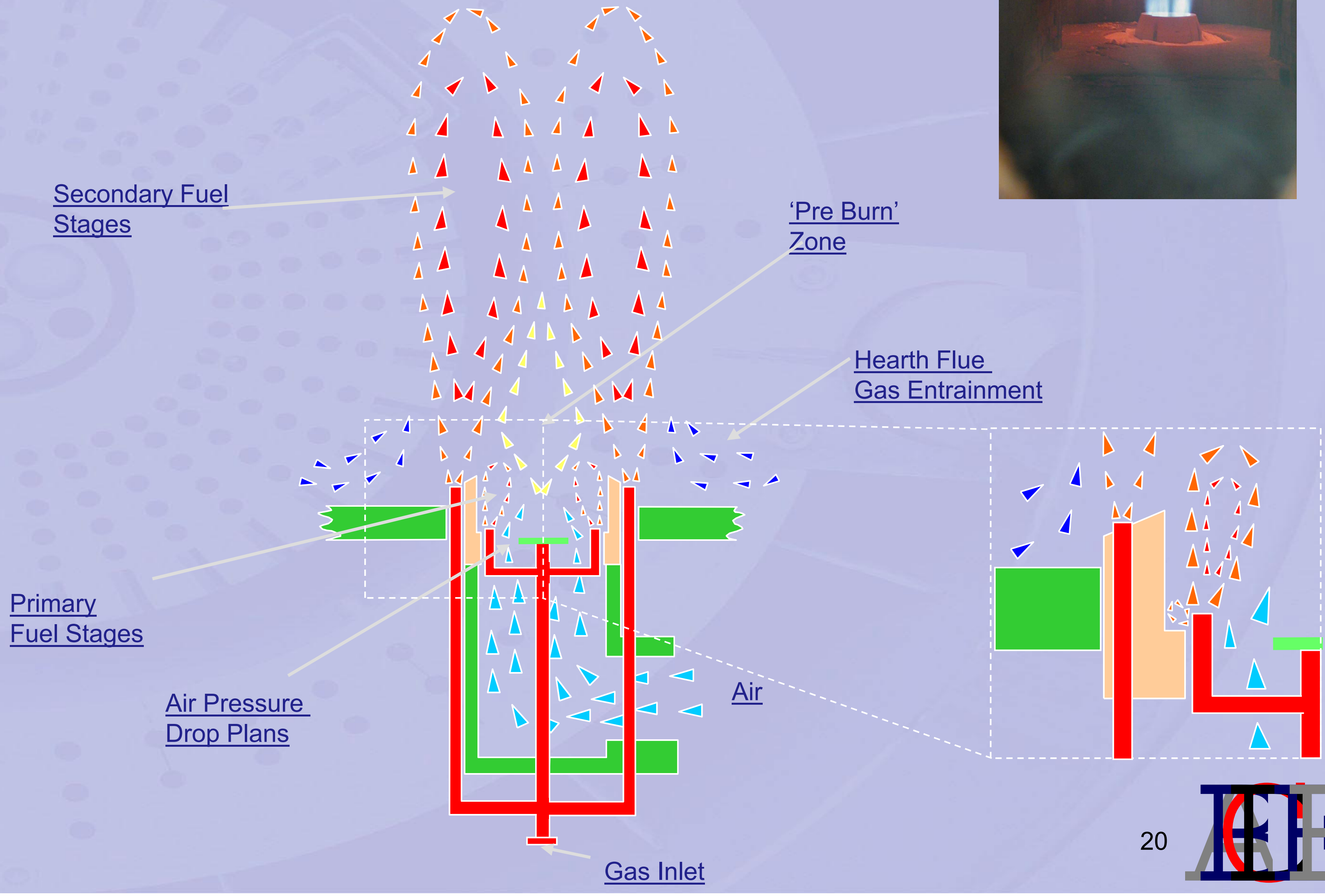
- Reviewing NOx reduction techniques in terms of staged fuel vs staged air vs staged combustion

Staged Air Burner
Flat Flame Burner Dynamics





Staged Fuel Burner
Round Flame Burner Dynamics



Staged Combustion

??????????????

Low NOx and Ultra LOw NOx Burners – Advantages Staged Air vs Staged Fuel

Staged Air	Staged Fuel
Less Potential for coking	Greater NOx reduction
Wider turndown	Easier set up
Less maintenance	
Increased flexibility	
Adjustable for changing gas cases	
Tighter flame dimensions	

Why????

Low NOx and Ultra LOw NOx Burners – Advantages Staged Air vs Staged Fuel

Reasons

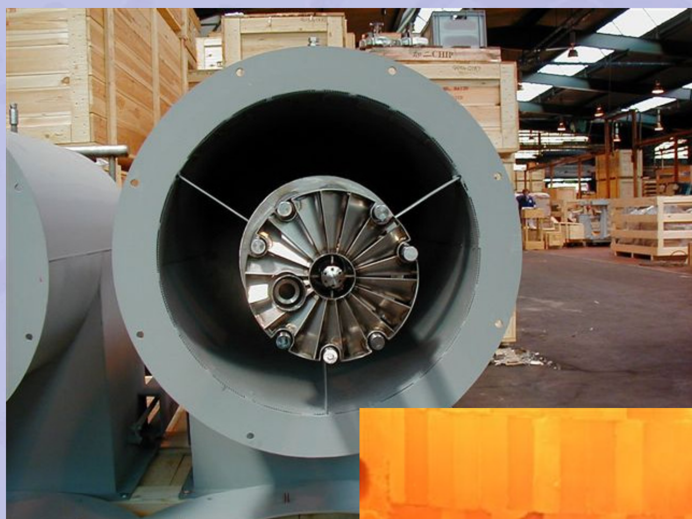
Staged Air	Staged Fuel
Single nozzle – larger orifices	Possible to adapt more severe staging
Air staging means as you decrease fuel burner becomes in ratio	Staging principle is fixed
Larger orifices / drillings	
Possibility to change staging principle	
Secondary air can be adjusted via separate damper	
Tile is smaller as no risers outside of tile	

Low NOx and Ultra LOw NOx Burners – Staged Air vs Staged Fuel – Nozzle Design

Staged Air Nozzle

Staged Fuel Nozzle

Low NOx and Ultra LOw NOx Burners – Staged Air/Staged Fuel – possible flame condition



Low NOx and Ultra Low NOx Burners – Factors for Consideration

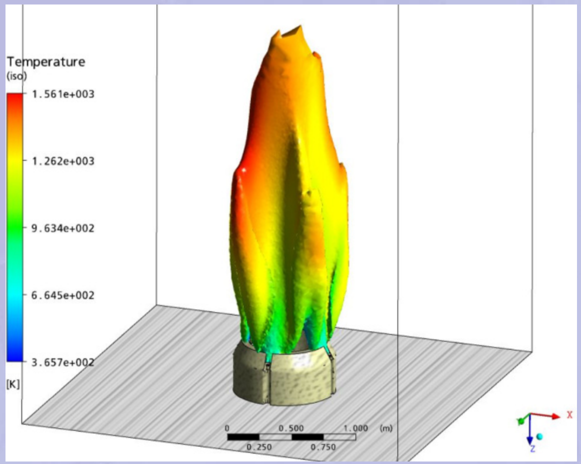
- The need for closer integration of end user, EPC, heater contractor and burner vendor

- The need for open honesty about what can and can not be achieved in order to avoid long term maintenance and operational issues.

Delayed Coking – Burner Design Considerations Future Requirements.....

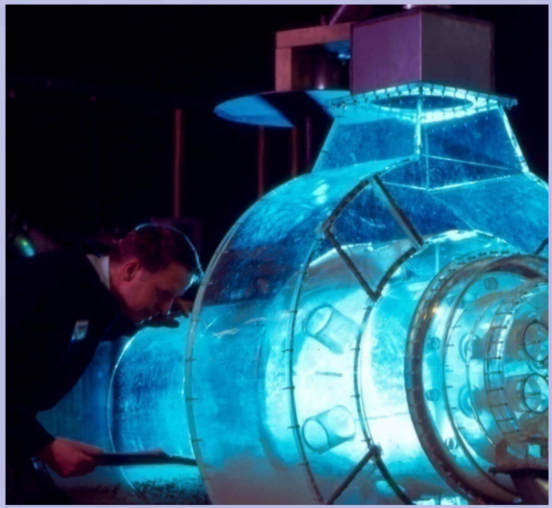
- Burners predominantly firing gas
- Low excess air levels – 5 to 10% (oil 20%)
- CO emissions of < 15 to 20 vppm
- Nox emissions of < 20 vppm for gas firing (150 vppm oil firing)
- UHC guarantees < 10 ppm
- Noise levels < 80-85 dB 'A'
- Turndown limits of 5:1
- Ability to meet emissions across all operating conditions
- Higher and more even heat flux (tighter flame shape)
- Possibly larger burners in restricted burner spacing to meet flux profile but keep capital cost low.
- Ultimately, Lower Capital cost, improved reliability, lower maintenance, lower emissions & higher efficinecy.

Delayed Coking – Burner Design Considerations Future Requirements.....



How to Achieve???

- Draw and expand on existing successful designs
- New Concepts
- Resolve Conflicts e.g
  - High furnace temperature vs NOx
  - Low flame temperature vs CO
  - Low Emissions vs Stability
  - Development using CFD and physical flow modelling
- Burner Test Firing
- Site Trials



Delayed Coking – Burner Design Considerations
Next Generation Burner Design Evaluation.....

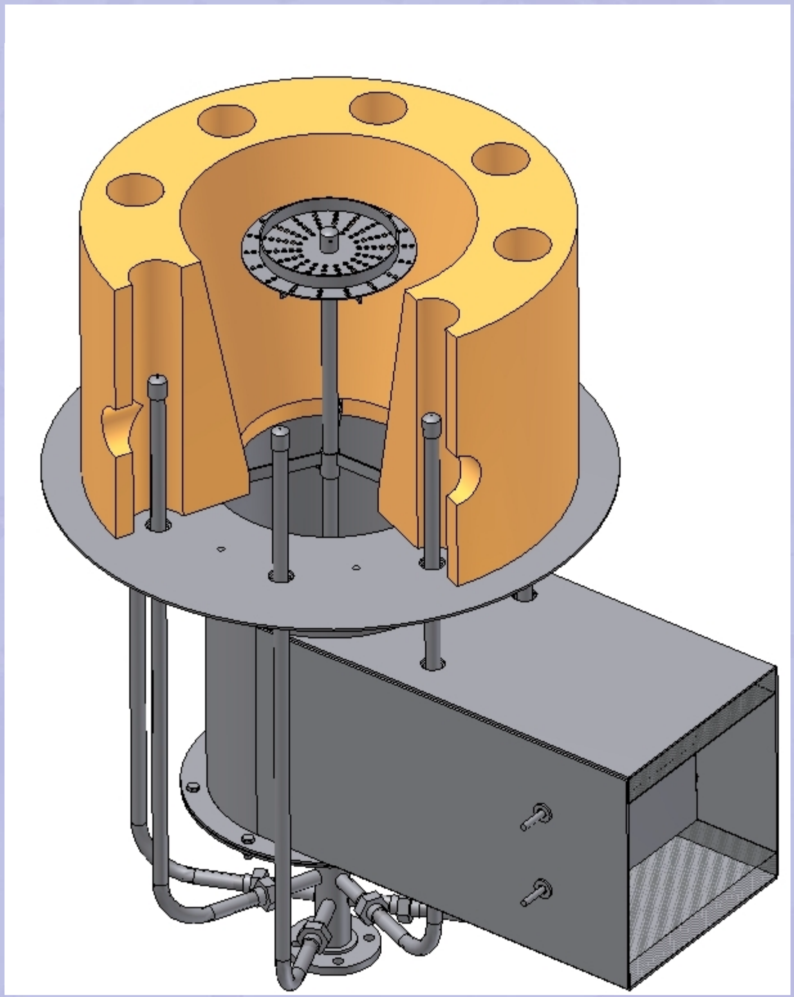
Typical NOx Reduction Technology:

- Fuel Staging
- Air Staging
- Flue Gas Recirculation (FGR)

- Staged fuel or staged air is used to delay combustion, minimise peak flame temperature
- Effect of FGR – adds heat but increases inerts and changes flame temperature / flammability range

Delayed Coking – Burner Design Considerations Alternative Technology – Staged Combustion.....

Staged Combustion / Flue Gas Re-Circulation Burner Dynamics



- Internal Flue Gas Recirculation
- Creates Superheated diluted fuel gas (analogous to a low CV gas)
- Rapid ignition on contact with combustion air – excellent stability
- Suitable for high hydrogen and heavy hydrocarbon gaseous fuels

Patent Pending

Advantages of Staged Combustion technology

- Simple burner design
- No complex low NOx gas nozzles
- Avoid pre-mix
- Stable operation / good burn-out
- Large turn-down range
- Even flame profile
- Suitable for wide range of fuel gas from hydrogen to heavy hydrocarbons
- Ultra Low NOx (10-15 v ppm??)
- Size range 1 – 20 MMBtu/hr

Advantages of Staged Combustion technology Cont'd....

1/4" orifice

Staged Air

3/8" orifice

Staged Combustion

Advantages of Staged Combustion technology Cont'd....

100% Natural Gas

20% Natural Gas / 80% H2

Necessities for Meeting End User Future Objectives

- Review of burner technology vs operating data and conditions.
- Increased openness within the industry regarding technology pro's and con's.
- Larger understanding of end user issues, equipment operability, maintenance requirements. (closer integration)
- Clarity in terms of end user emission guarantee requirements – avoid adding safety margin on safety margin
- Realisation that a price driven market may not always offer the way forward in terms of achieving optimum furnace operation.

Questions????

- Is Ultra Low NOx the best solution if the operating and maintenance cost of equipment outweigh the cost associated with additional SCR catalyst?
- Is it possible moving forward with furnace designs that flame flame burners can be accepted as round flame design?
- Are local EPA requirements clearly visible between end user, EPC, heater vendors & equipment suppliers during conceptual design stages of a project?
- Do we all know of or have been involved with a furnace where operation could have been improved from an alternative review of burner selection?