Gas Burner Technology
&
Gas Burner Design for Application

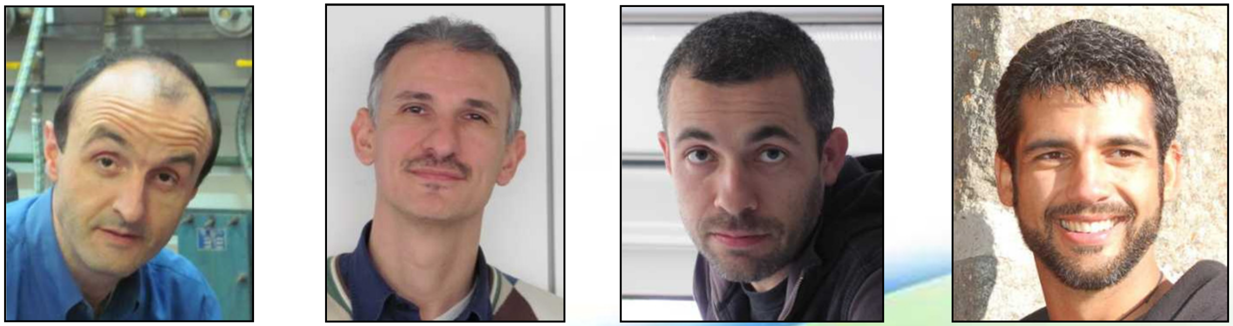
WORGAS®

ENERGY TRANSFORMATION TECHNOLOGY

Dr. Gunther Bethold Managing Director

Dr.Luca Barozzi
Ing. Massimo Dotti
Ing. Massimo Gilioli
Dr. Gabriele Gangale

} Engineering Staff



Index

What is a Burner?

Device which enables a chemical reaction of fuel and oxidizer (usually Oxygen from air) to produce heat in a controlled way.

wall hung boilers storage water heater cookers

decorative fireplaces hot air generator washer

Heater or dryer for industrial application (steel , glass, food)

Theoretical Stoichiometric Combustion

complete oxidation of a fuel with no excess air (lambda = ratio air/gas =1):

(e.g. global reaction Methane & Propane)

$CH_4 + 2(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + 7.52N_2$ -889kJ

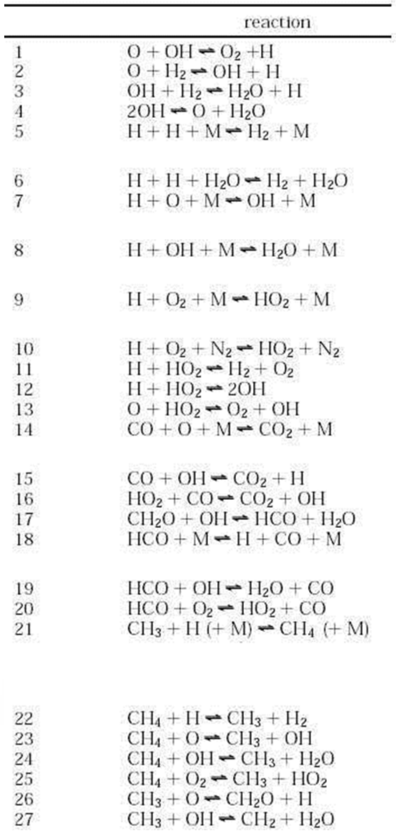
$C_3H_8 + 5(O_2 + 3.76N_2) \rightarrow 3CO_2 + 4H_2O + 18.7N_2$ – 2220 kJ

Standard conditions 1 atm. and 25 C

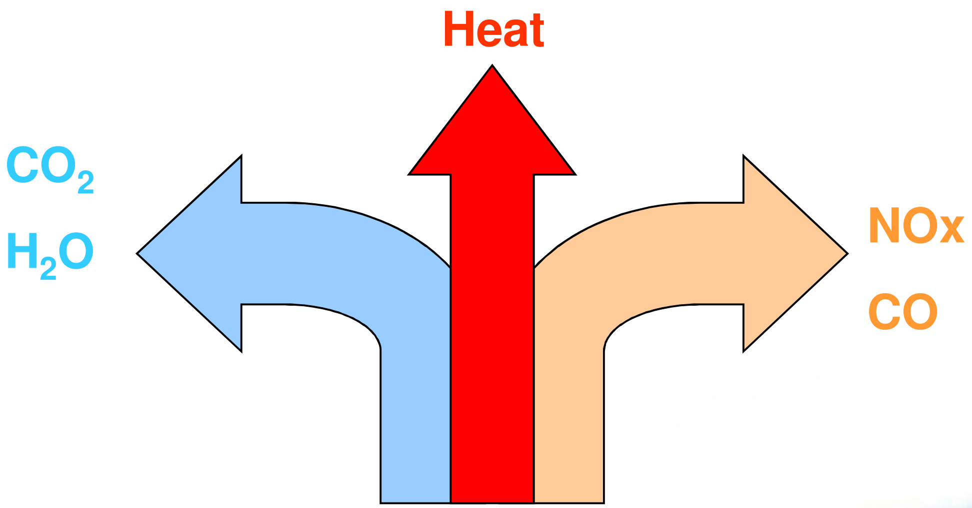
Combustion Reaction & Products

In reality :
Complete real mechanism is composed of thousands of reactions

Not all reaction come to full completion, giving as a result pollutant emissions



	reaction
1	$O + OH \rightleftharpoons O_2 + H$
2	$O + H_2 \rightleftharpoons OH + H$
3	$OH + H_2 \rightleftharpoons H_2O + H$
4	$2OH \rightleftharpoons O + H_2O$
5	$H + H + M \rightleftharpoons H_2 + M$
6	$H + H + H_2O \rightleftharpoons H_2 + H_2O$
7	$H + O + M \rightleftharpoons OH + M$
8	$H + OH + M \rightleftharpoons H_2O + M$
9	$H + O_2 + M \rightleftharpoons HO_2 + M$
10	$H + O_2 + N_2 \rightleftharpoons HO_2 + N_2$
11	$H + HO_2 \rightleftharpoons H_2 + O_2$
12	$H + HO_2 \rightleftharpoons 2OH$
13	$O + HO_2 \rightleftharpoons O_2 + OH$
14	$CO + O + M \rightleftharpoons CO_2 + M$
15	$CO + OH \rightleftharpoons CO_2 + H$
16	$HO_2 + CO \rightleftharpoons CO_2 + OH$
17	$CH_2O + OH \rightleftharpoons HCO + H_2O$
18	$HCO + M \rightleftharpoons H + CO + M$
19	$HCO + OH \rightleftharpoons H_2O + CO$
20	$HCO + O_2 \rightleftharpoons HO_2 + CO$
21	$CH_3 + H\ (+ M) \rightleftharpoons CH_4\ (+ M)$
22	$CH_4 + H \rightleftharpoons CH_3 + H_2$
23	$CH_4 + O \rightleftharpoons CH_3 + OH$
24	$CH_4 + OH \rightleftharpoons CH_3 + H_2O$
25	$CH_4 + O_2 \rightleftharpoons CH_3 + HO_2$
26	$CH_3 + O \rightleftharpoons CH_2O + H$
27	$CH_3 + OH \rightleftharpoons CH_2 + H_2O$



Heat

CO_2

H_2O

NOx

CO

Combustion Reaction & Products

Higher (HHV) and Lower (LHV) Heating values

HHV = LHV + h*v* x (nH2O,out/nfuel,in)

h*v* : heat of vaporization of water,
nH2O,out : moles of water vaporized
nfuel,in: moles of fuel combusted

Fuel	HHV MJ/kg	HHV BTU/lb	HHV kJ/mol	LHV MJ/kg
Hydrogen	141.80	61,000	286	121.00
Methane	55.50	23,900	889	50.00
Ethane	51.90	22,400	1,560	47.80
Propane	50.35	21,700	2,220	46.35
Butane	49.50	20,900	2,877	45.75

Combustion Reaction & Products

- $CH_4 + 2(O_2 + 3.76N_2) \rightarrow CO_2 + 2H_2O + 7.52N_2$ + enthalpy
  - CO2 max %= 1 / (1 + 7,52) x 100 = 11,46 % (dry condition)

    you need to get the water out of the exhaust gas for the analysis – damage of instrument
  - O2 % = 21% for no combustion, = 0% for complete combustion
  - O2 % = 21% – 21/11,46 x CO2 meas. %

Combustion Reaction & Products

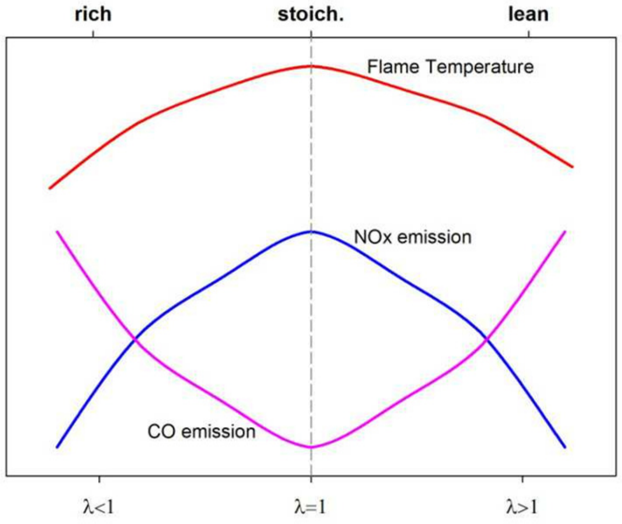
Stoichiometrical reactions in most cases are not advantageous therefore

we predominately work in excess air conditions

l = Air / fuel ratio = 1 / F
F = Fuel / air ratio

(e.g.20% Excess Air $\lambda = 1.2$)

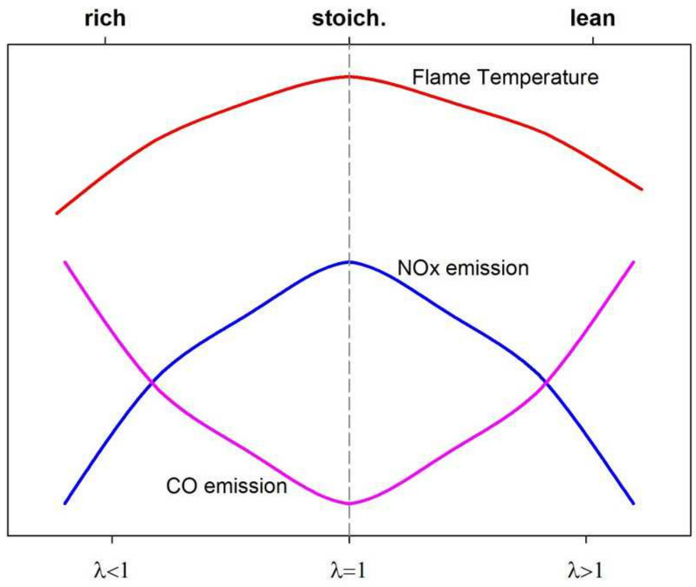
$CH_4 + 2.4O_2 + 8.3N_2 \rightarrow CO_2 + 2H_2O + 0.4O_2 + 8.3N_2$



Combustion Reactions & Products

NOX formation

- Fuel NOX – Nitrogen contained within the fuel, particularly gases containing ammonia. Since Natural Gas contains no Nitrogen this mechanism does not apply for methane.
- Thermal NOX (Zeldovich) – occurs at high temps (>1800K) and is predominately NO.
- Prompt NO – occurs at low temps in fuel rich flame regions and can be significant in Natural gas flames.



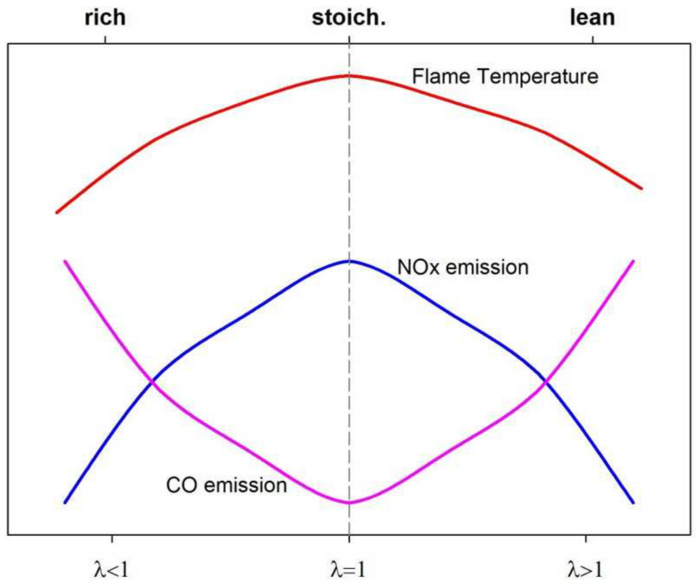
Combustion Reactions & Products

CO formation

(a) Poor combustion control (flame stability, mixing etc).

(b) Flame impact/quenching against cold surfaces (loses heat quickly)

(c) Equilibrium dissociation of $CO_2 \Leftrightarrow CO$



Combustion Reactions & Products

A burner design can not be developed without insight on:

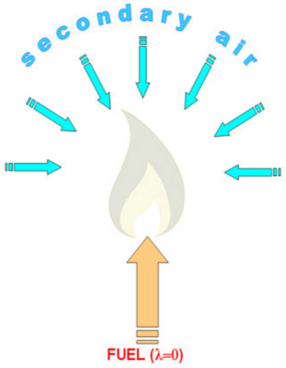
- Air / fuel ratio – atmospheric vs premix
- Modulation range
- Reaction chemistry influence
- Temperature effect (quenching of flame, external cooling or heating elements)

Combustion Reactions & Products

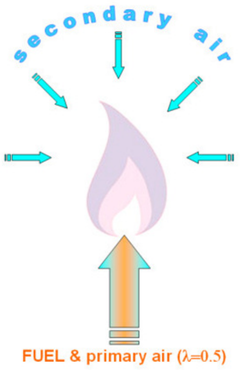
Air / Fuel ratio **Atmospheric vs. fan assisted** **Aerated vs. premix**

Aside from fixing l , it must also be investigated the effect of SECONDARY AERATION to the flame and how this secondary air reach the combustion area

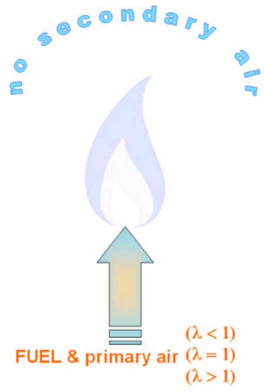
ATMOSPHERIC



PARTIALLY PREMIXED

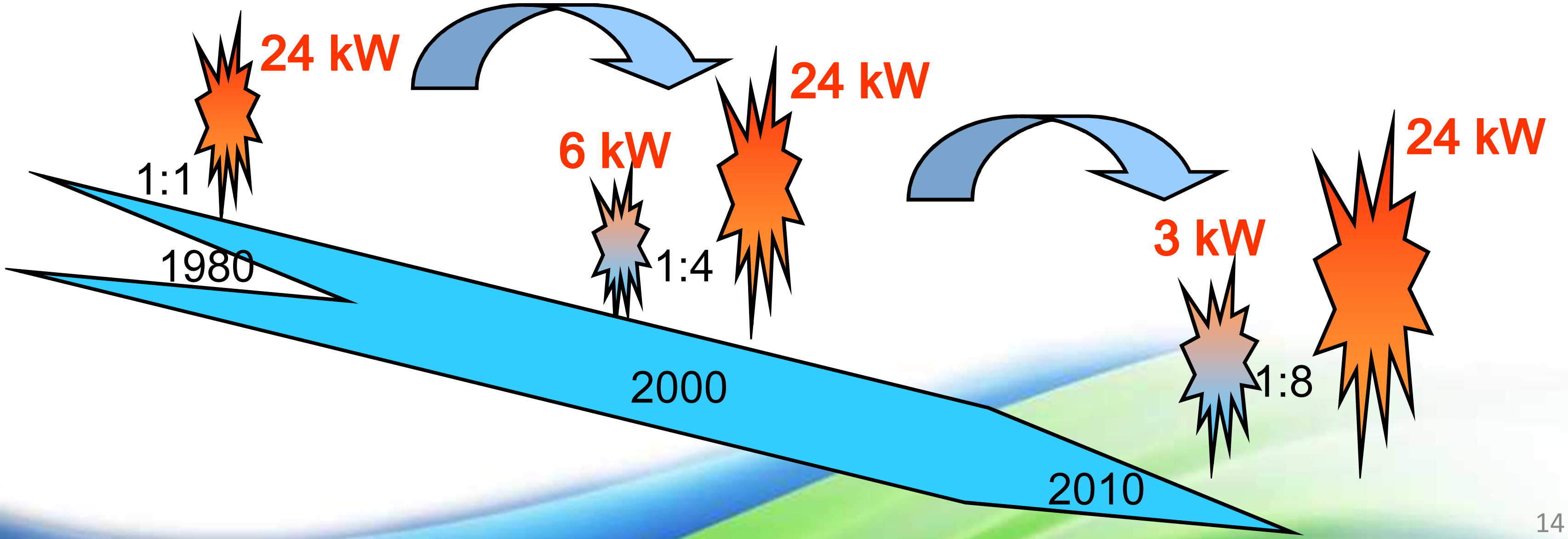


FULLY PREMIXED

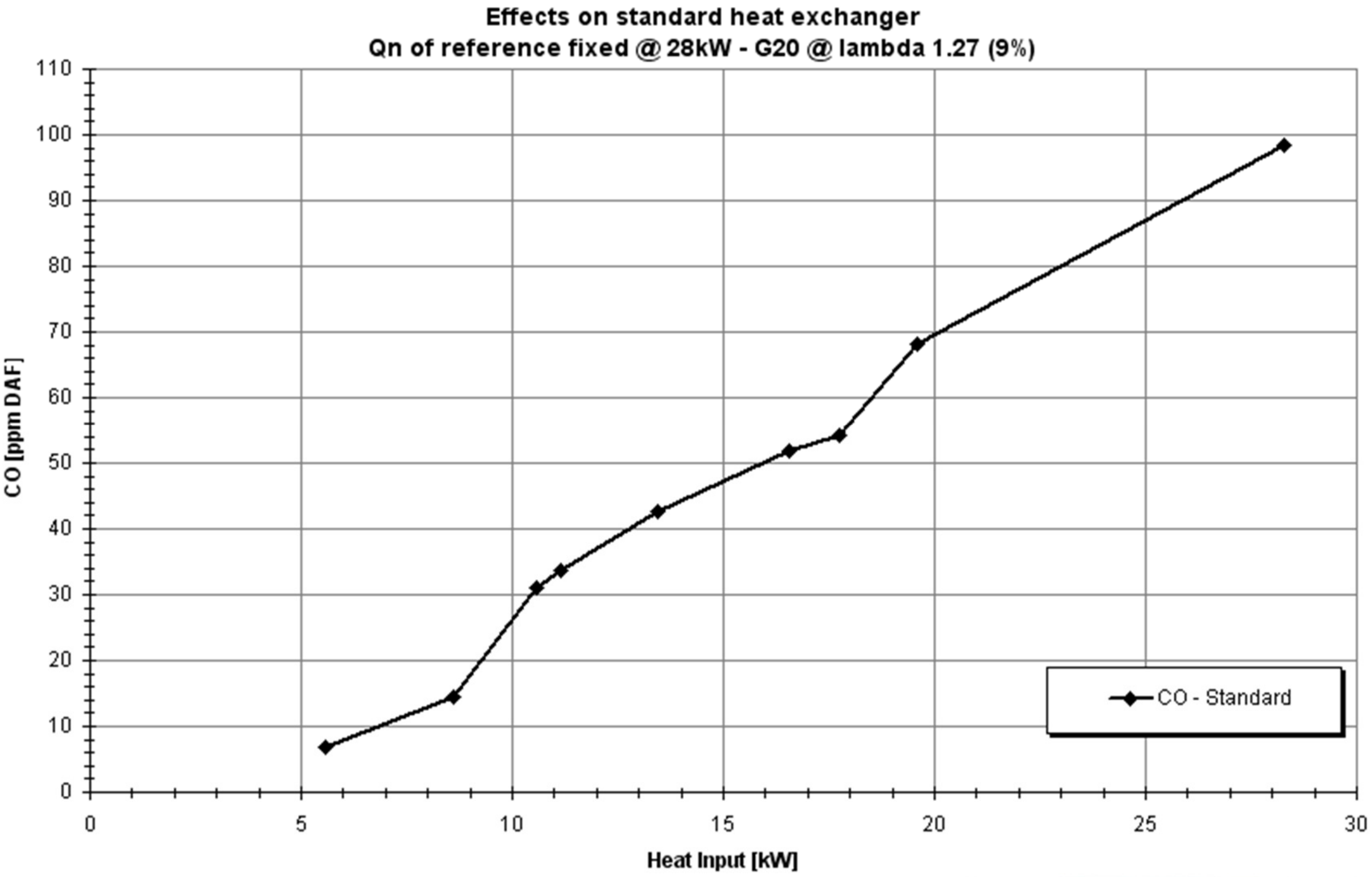


Turn down ratio

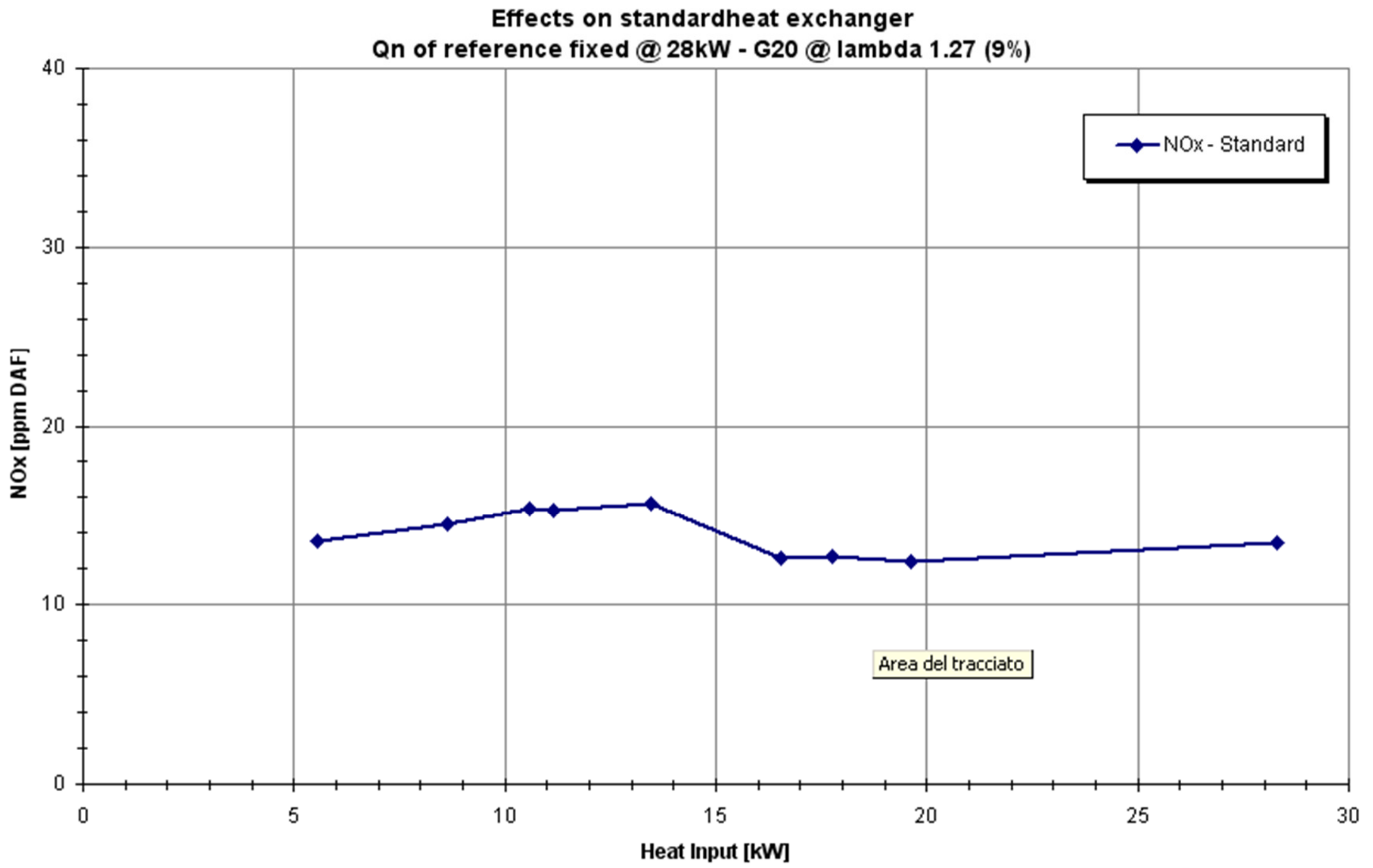
Turn down ratio decreased as the heating units evolved to condensing. This maximises efficiency (decreases stand-by losses and number of burner start) decreases NOx and CO emissions and decreases power consumption,



Emission VS Modulation Range

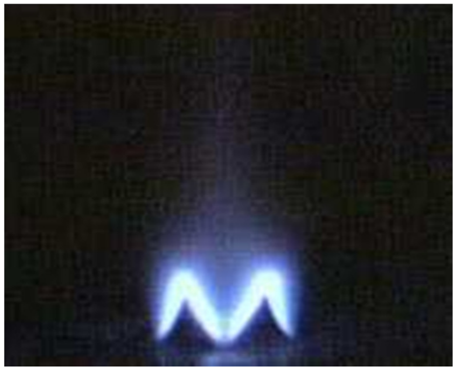


Emission VS Modulation Range

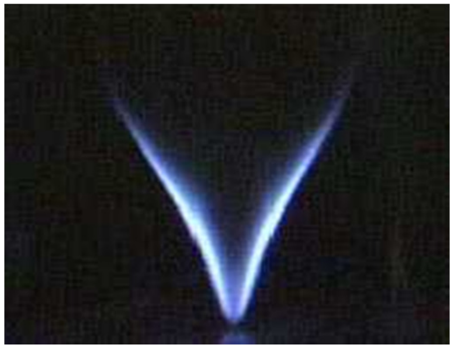


Flame VS Modulation Range

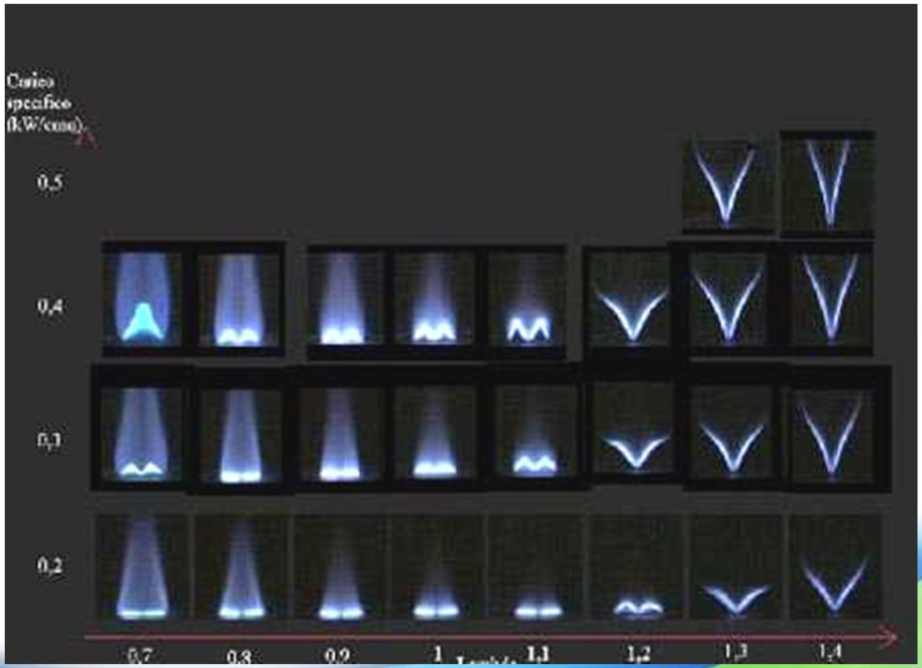
$\lambda = 0.7$ ps = 0.4 kW/cm^2



$\lambda = 1.1$ ps = 0.4 kW/cm^2



$\lambda = 1.3$ ps = 0.4 kW/cm^2



Flame behavior for different lambda and specific load

Reaction chemistry influence

It is possible to affect chemistry directly introducing catalytic elements .

It is possible to accelerate or delaying the completeness of the reactions affecting the residential time inside a combustion chamber / HE

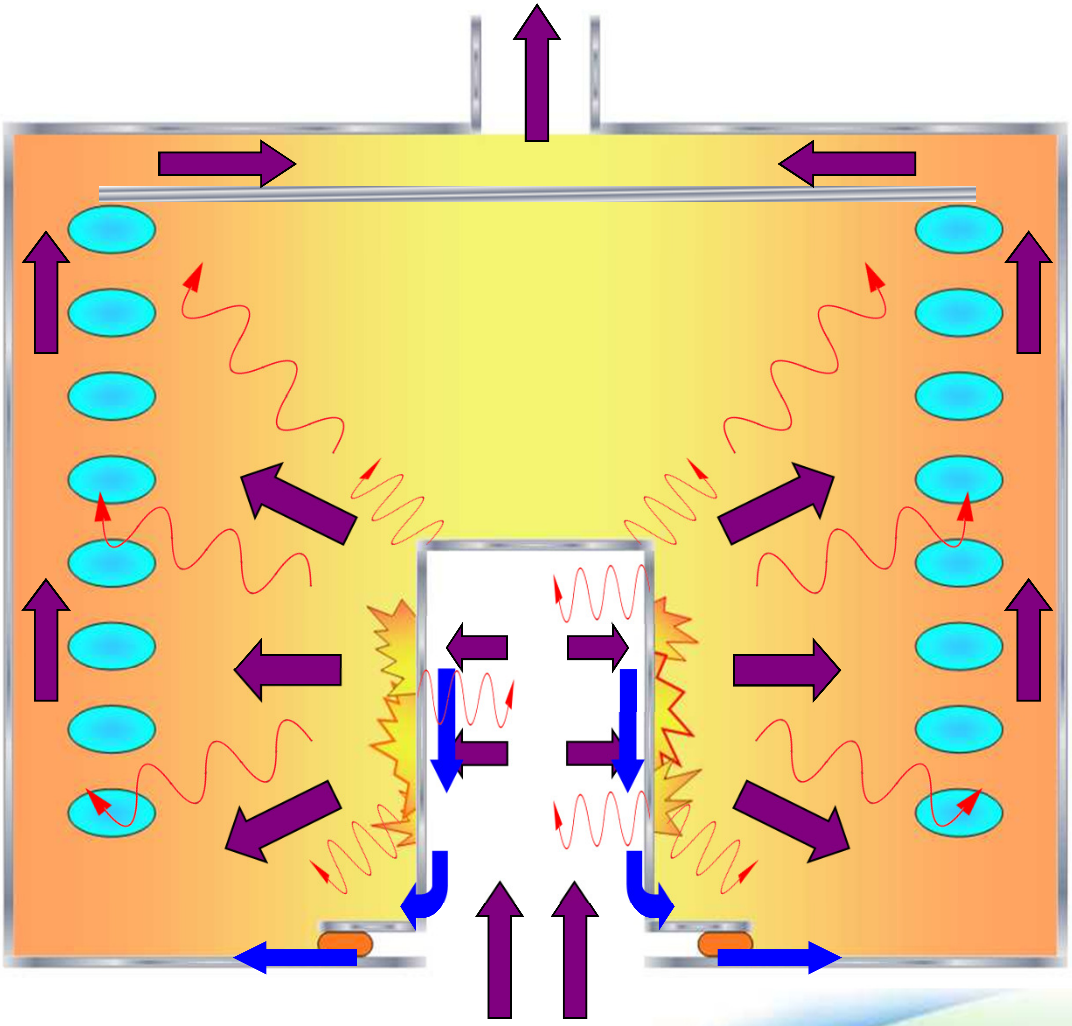
Switching from laminar to turbulent fluid dynamics

Temperature effect

It is possible to accelerate or delaying the completeness of the reactions introducing or removing heat to the reacting flow (e.g steel or ceramic rod into the flame)

The combustion chamber wall and/or the HE too close to the flame front, or any element that move/transfer heat from the combustion area to the surrounding HAS a deep impact on the emissions.

Heat Transfer Effects



Heat Transfer Effects

The weight of conduction , convection and radiation changes according to the mode of working of the burner.

A burner may operate from blue flame mode to radiation mode

Example Nox Reduction Techniques

The majority of NO_X produced is temperature dependent therefore ways of lowering combustion temperatures is attempted;

(a) Lean Burn – results in cooler flames, systems are run at ≥20% excess air.
(b) Low Residence time
(c) Well mixed systems
(d) Insert of radiating rod to cool the flame
(e) Inserts downstream of peak flame area

Burner Types

Burner Types

Premix

(a) Fan powered so that the fuel/air ratio can be carefully controlled.

(b) Run lean (≥20%) with NO_X emissions < 45 mg/kWh

(c) Typically produce short intense blue flames

(d) Short reaction zones and the highest burning velocities hence the smallest residence times & high efficiencies

(e) The heat exchanger can (and should) be located very close to cool the exhaust as quickly as possible to avoid NO_X formation.

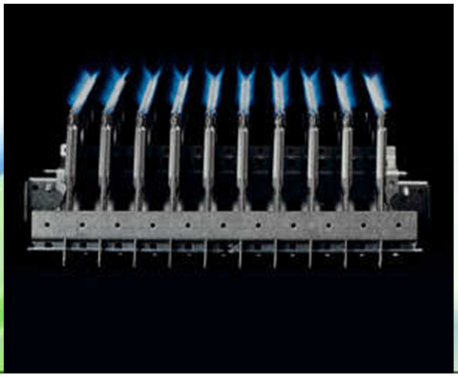
Atmospheric

(a) Most common type of domestic burner (tube arrays, blade assemblies), low cost manufacture with little maintenance.

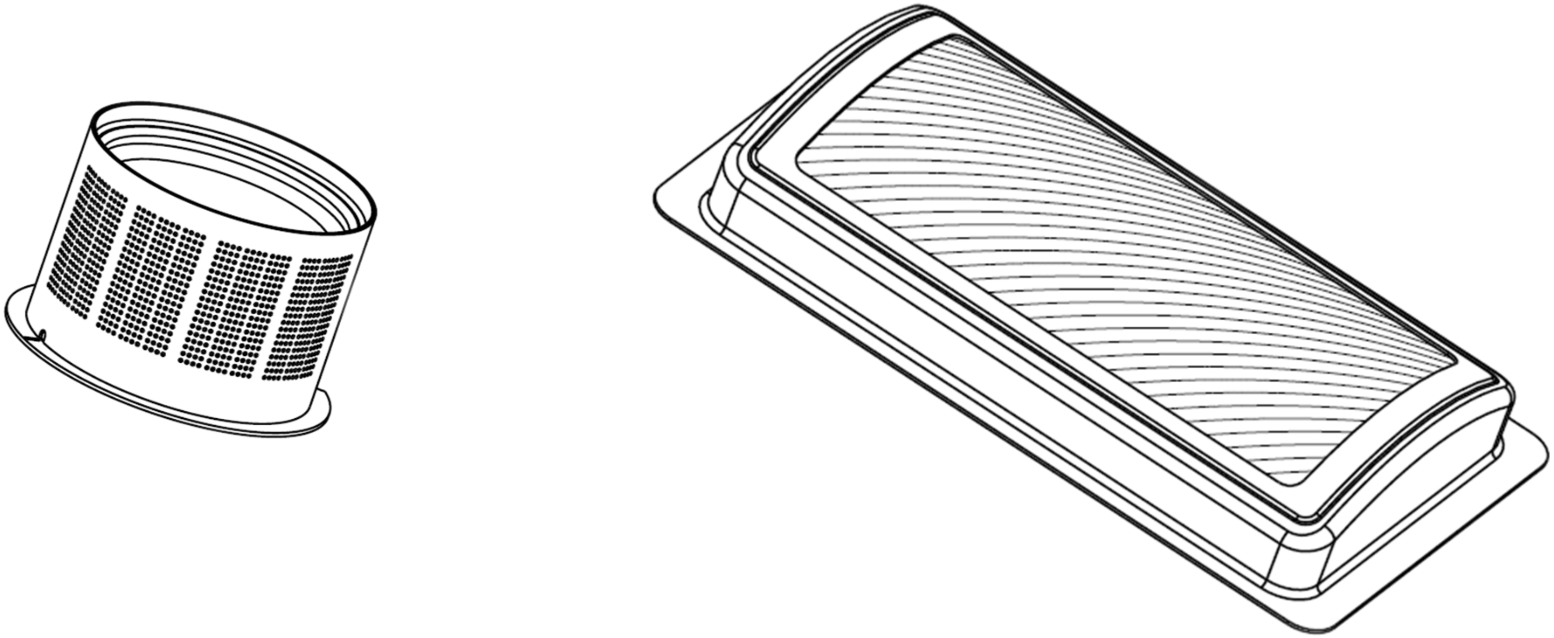
(b) Partially premixing (air entrained into gas stream before burner) to lower flame temperature.

(c) Run on a rich/air mix to form inner combustion zone, preventing thermal NOx with low O concentration.

(d) Tend to give relatively large flame volumes giving longer residence times for NO_X production to occur.

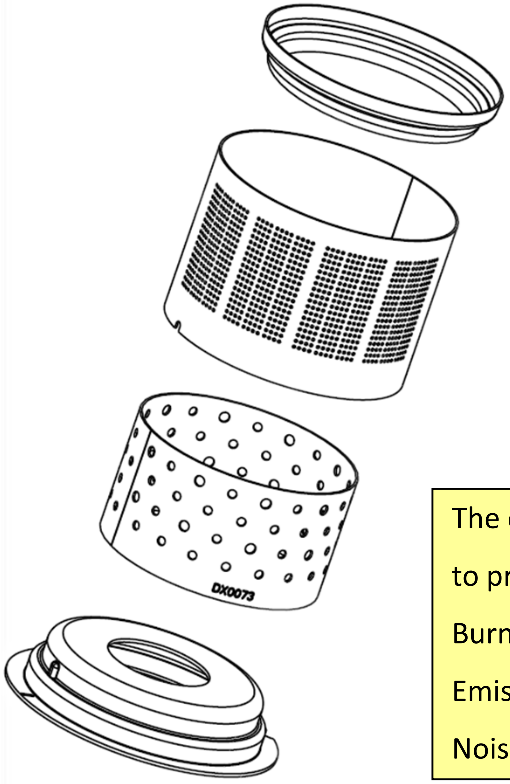


Design for Application



Design for most common premix burners

Design for Application



The front flange , or frame , of a burner defines the interaction between burner and mixture inlet duct. It is, and must be, a component hight customizable

The distributor , one or more, is necessary to properly arrange the mixture flow on the Burning body. It is a key element that affects:

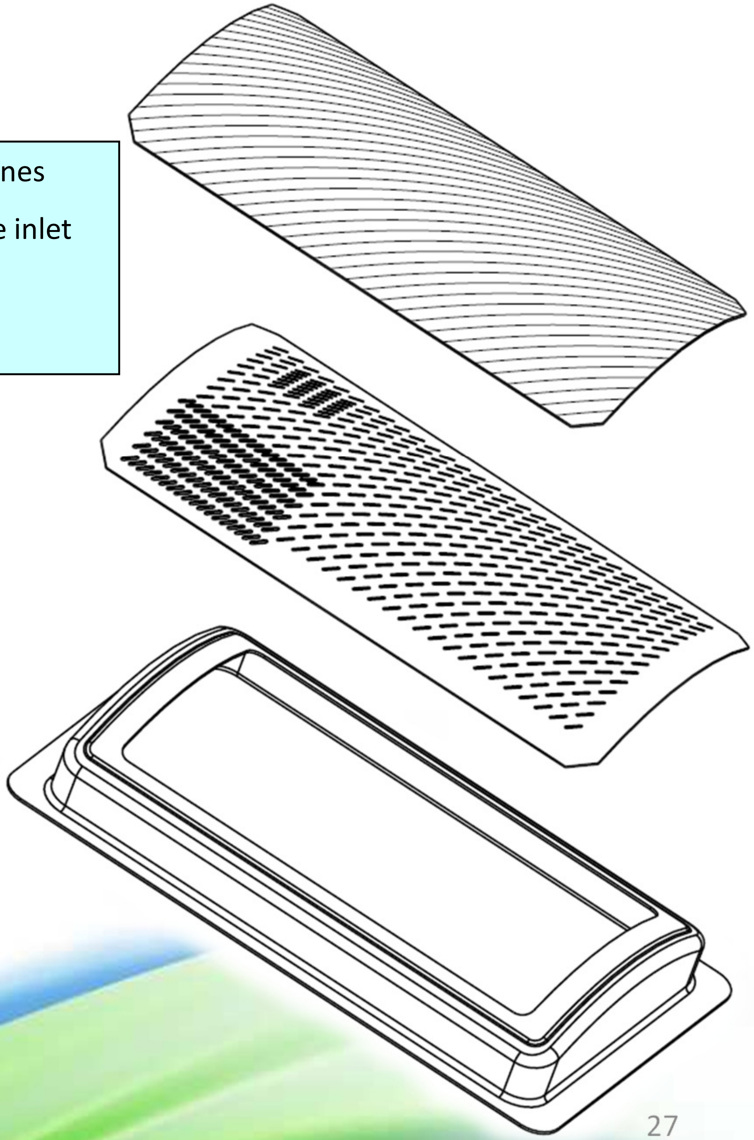
Emissions

Noise behaviour

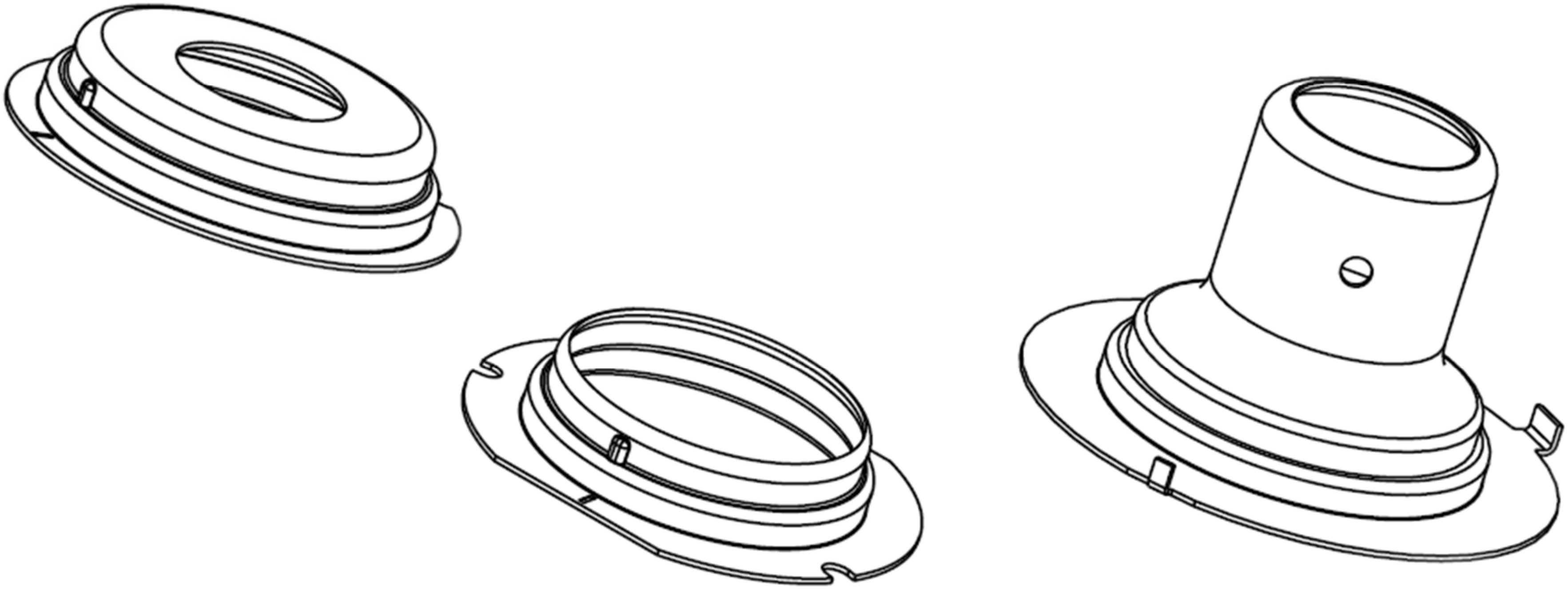
The burner body , or flame diffuser, is the most important component – in contact with the flame region. It is a key element that affects :

Modulation and emission

Noise behaviour



Design of Application



Example of customization of the front flange.

Design for Application

Cylindrical premix : full metal vs fiber fabric

Flat ceramic burner

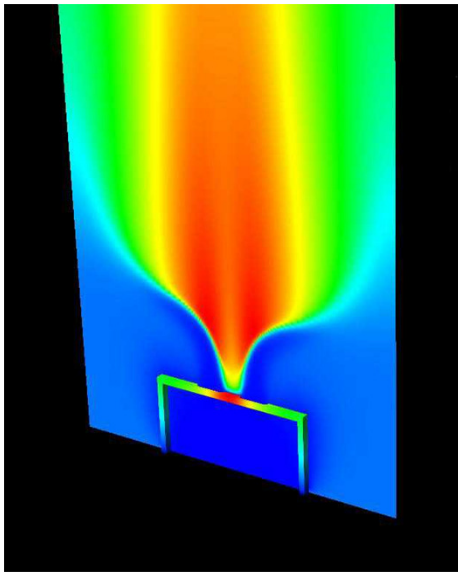
Flat metal

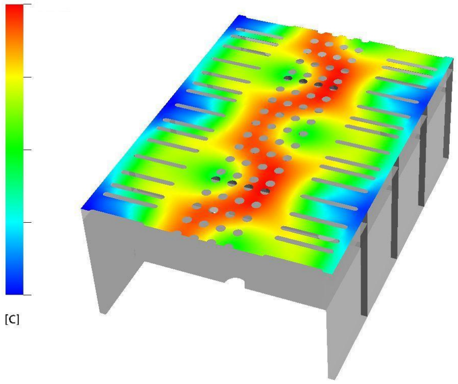
Design for Application

Design for Application - CFD

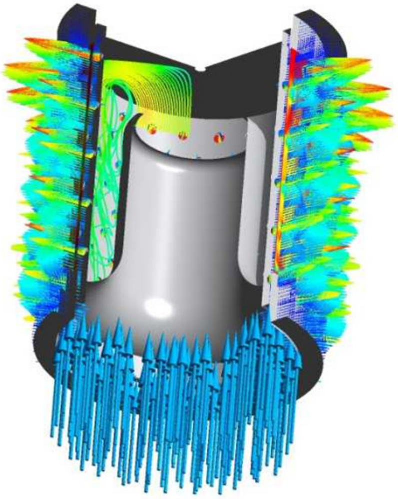
Flame shape analysis

Temperature field on fluids and solid materials





Gas mixture



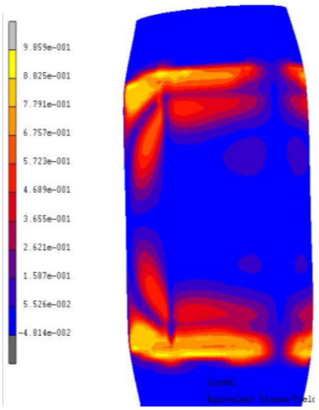
Pressure drops

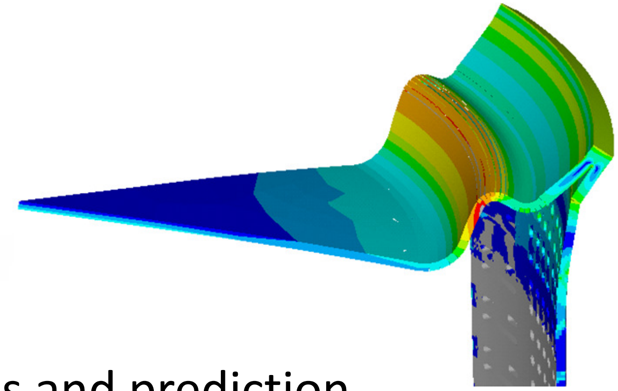
Design for Application - FEM

Strain and stress analysis

Welding analysis & design

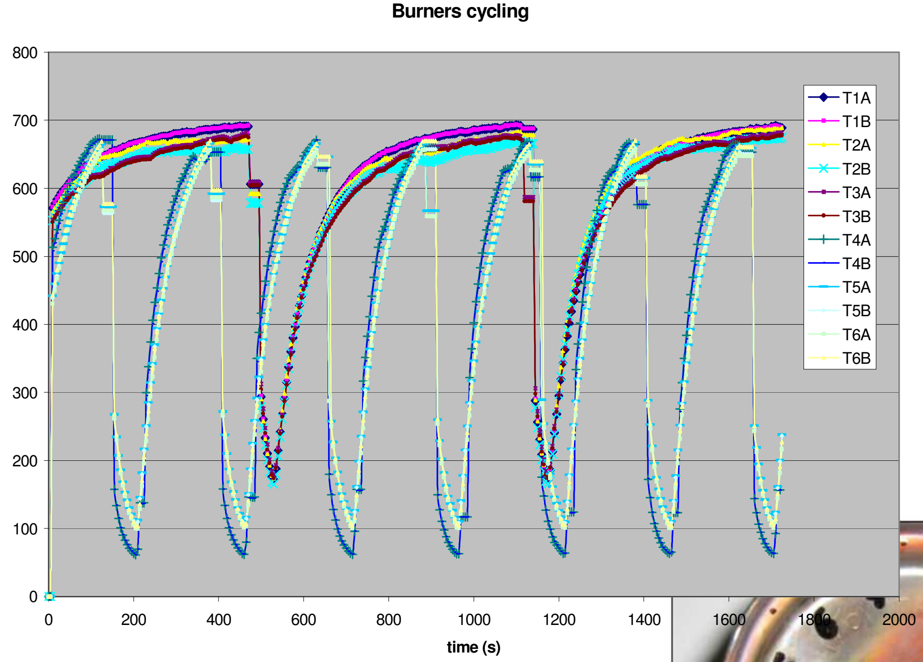
Non-linear buckling analysis



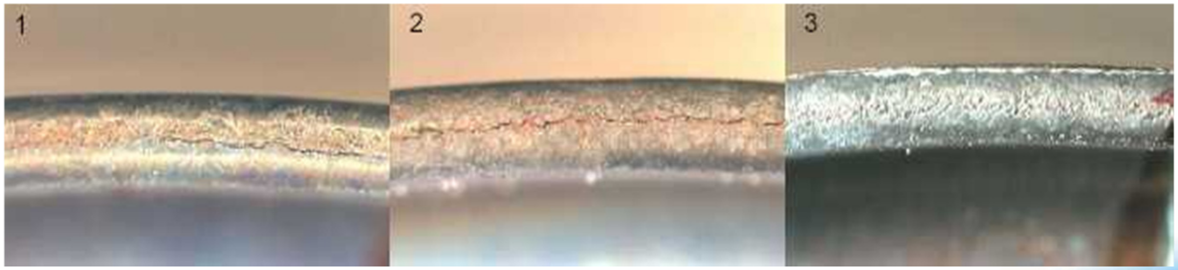


Failure analysis and prediction

Design for Application – Life Tests

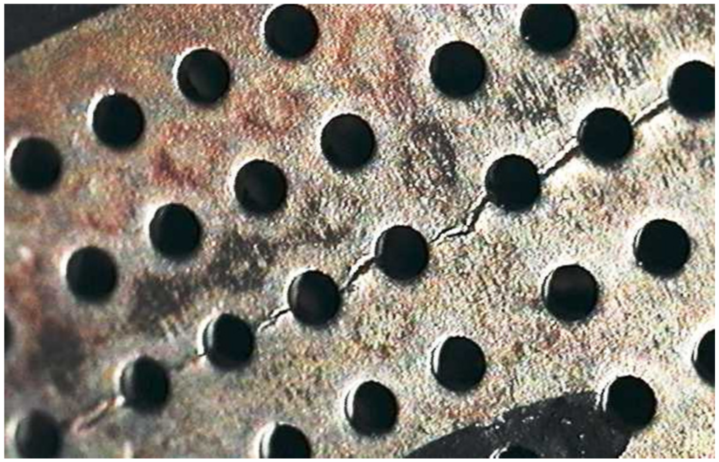


Thermal cycling for accelerated life tests



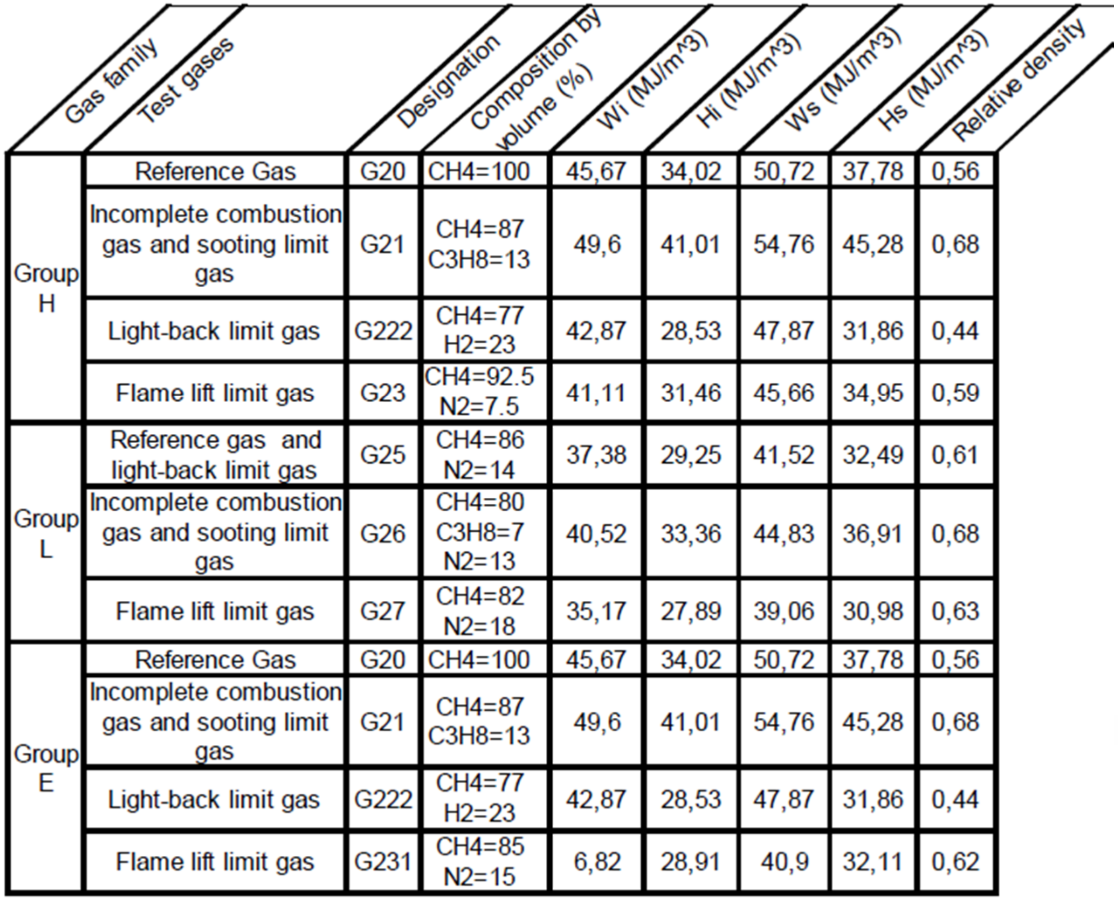
Design for Application – Structural Failure

Crack on a metal surface of the diffuser due to thermal cycling



Test Gas & Interchangeability of Gases

Test gas for second family, T=15°C, p1013,25mbar



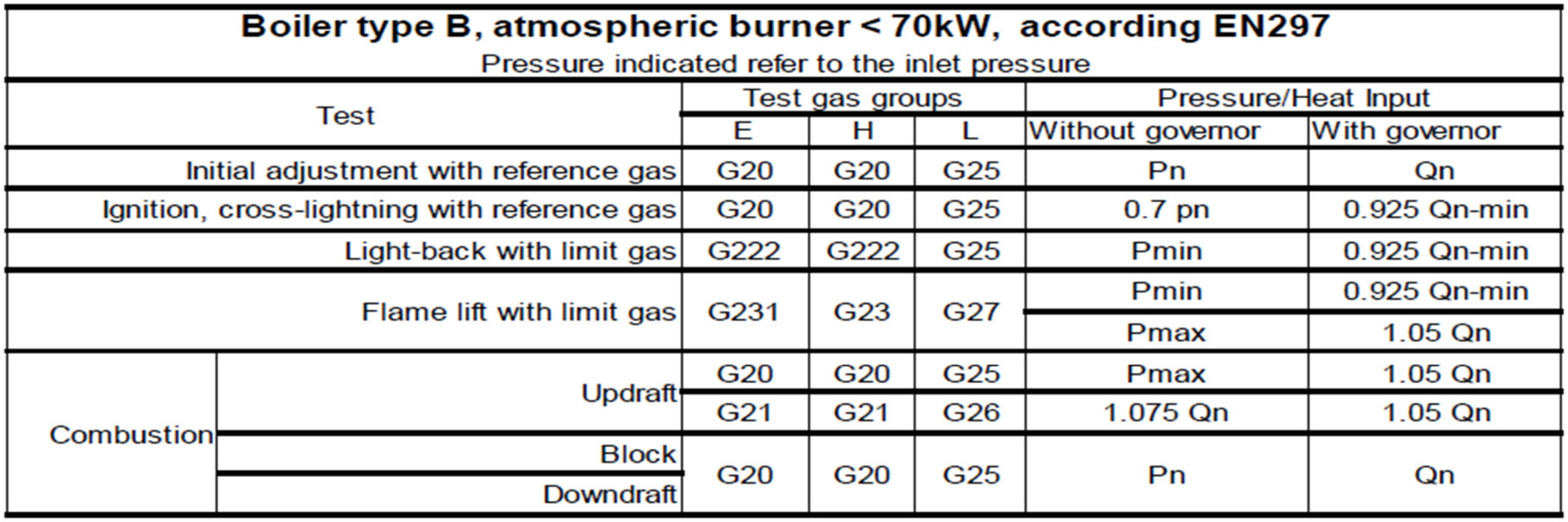
Gas family	Test gases	Designation	Composition by volume (%)	Wi (MJ/m^3)	Hi (MJ/m^3)	Ws (MJ/m^3)	Hs (MJ/m^3)	Relative density
Group H	Reference Gas	G20	CH4=100	45,67	34,02	50,72	37,78	0,56
	Incomplete combustion gas and sooting limit gas	G21	CH4=87 C3H8=13	49,6	41,01	54,76	45,28	0,68
	Light-back limit gas	G222	CH4=77 H2=23	42,87	28,53	47,87	31,86	0,44
	Flame lift limit gas	G23	CH4=92.5 N2=7.5	41,11	31,46	45,66	34,95	0,59
Group L	Reference gas and light-back limit gas	G25	CH4=86 N2=14	37,38	29,25	41,52	32,49	0,61
	Incomplete combustion gas and sooting limit gas	G26	CH4=80 C3H8=7 N2=13	40,52	33,36	44,83	36,91	0,68
	Flame lift limit gas	G27	CH4=82 N2=18	35,17	27,89	39,06	30,98	0,63
Group E	Reference Gas	G20	CH4=100	45,67	34,02	50,72	37,78	0,56
	Incomplete combustion gas and sooting limit gas	G21	CH4=87 C3H8=13	49,6	41,01	54,76	45,28	0,68
	Light-back limit gas	G222	CH4=77 H2=23	42,87	28,53	47,87	31,86	0,44
	Flame lift limit gas	G231	CH4=85 N2=15	6,82	28,91	40,9	32,11	0,62

A burner has to cover a wide range of gas qualities regarding emissions, stability, ignition, input rate, modulation

- The "reference gas" is close to the local line gas quality.
- The limit gases test for
  - * flame lift: light gas with N2
  - * flash back: high burning velocity through H2
  - * Incomplete combustion or sooting: with higher calorfic gases
- Group H: Italy, Group E: Germany, Group L: Netherlands

Test Gas & Interchangeability of Gases

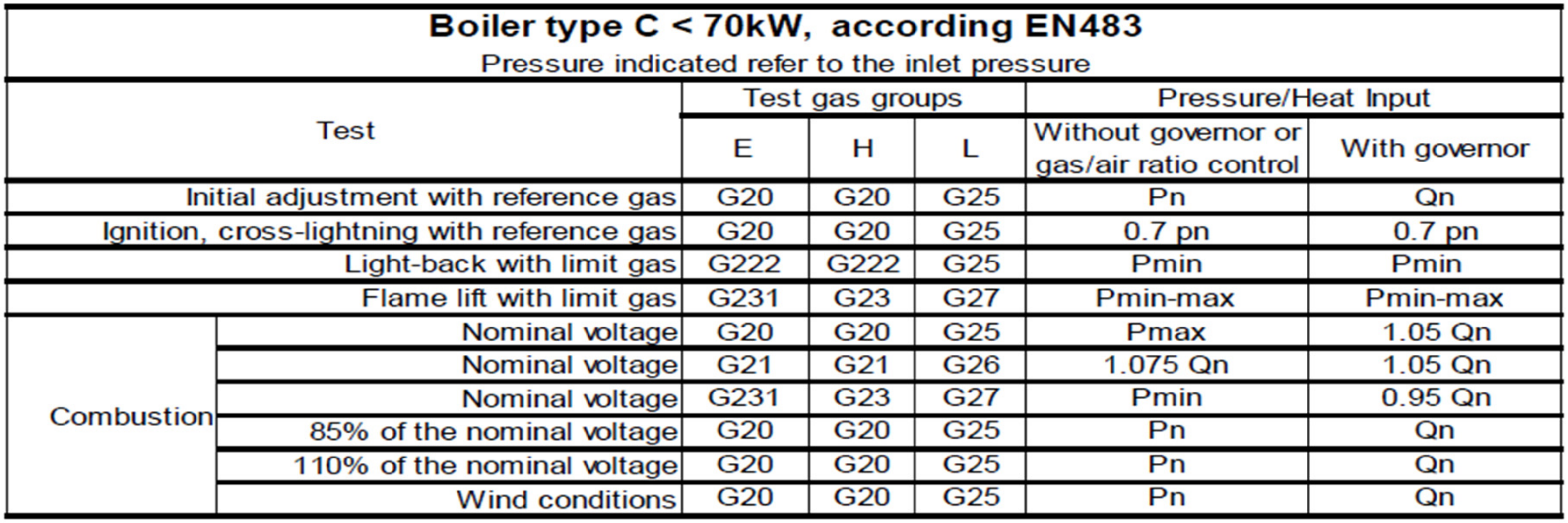
Test program: defined by standards + appliance manufacturer



Boiler type B, atmospheric burner < 70kW, according EN297

Pressure indicated refer to the inlet pressure

Test		Test gas groups			Pressure/Heat Input	
		E	H	L	Without governor	With governor
Initial adjustment with reference gas		G20	G20	G25	Pn	Qn
Ignition, cross-lightning with reference gas		G20	G20	G25	0.7 pn	0.925 Qn-min
Light-back with limit gas		G222	G222	G25	Pmin	0.925 Qn-min
Flame lift with limit gas		G231	G23	G27	Pmin	0.925 Qn-min
					Pmax	1.05 Qn
Combustion	Updraft	G20	G20	G25	Pmax	1.05 Qn
		G21	G21	G26	1.075 Qn	1.05 Qn
	Block Downdraft	G20	G20	G25	Pn	Qn

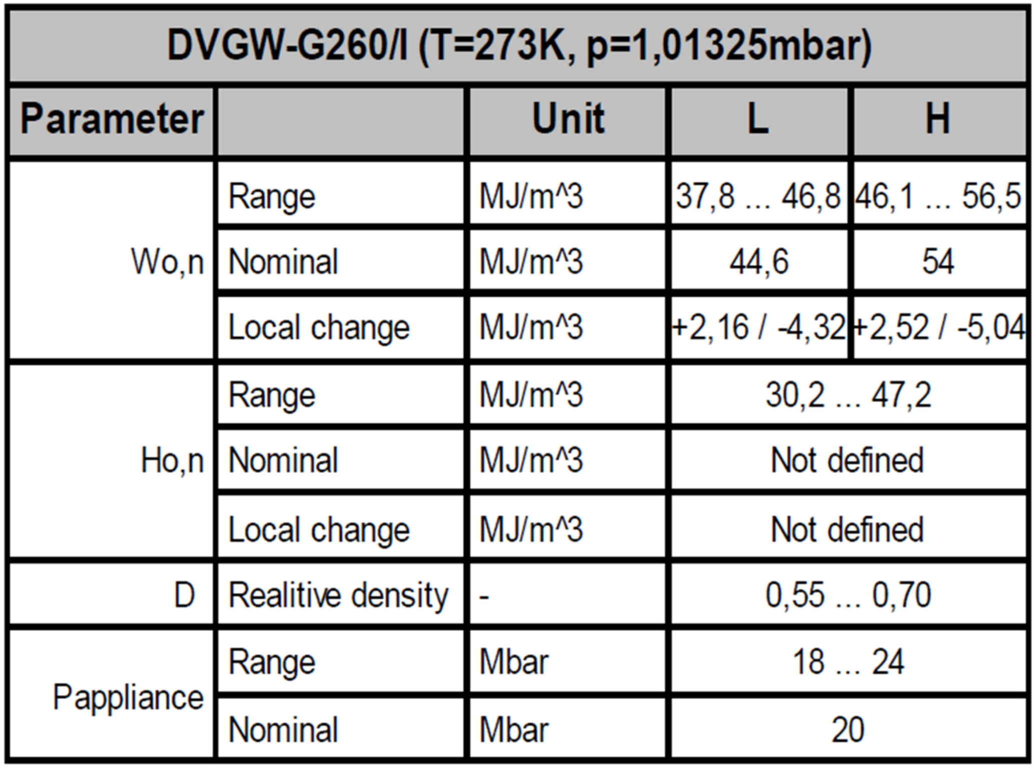


Boiler type C < 70kW, according EN483

Pressure indicated refer to the inlet pressure

Test		Test gas groups			Pressure/Heat Input	
		E	H	L	Without governor or gas/air ratio control	With governor
Initial adjustment with reference gas		G20	G20	G25	Pn	Qn
Ignition, cross-lightning with reference gas		G20	G20	G25	0.7 pn	0.7 pn
Light-back with limit gas		G222	G222	G25	Pmin	Pmin
Flame lift with limit gas		G231	G23	G27	Pmin-max	Pmin-max
Combustion	Nominal voltage	G20	G20	G25	Pmax	1.05 Qn
	Nominal voltage	G21	G21	G26	1.075 Qn	1.05 Qn
	Nominal voltage	G231	G23	G27	Pmin	0.95 Qn
	85% of the nominal voltage	G20	G20	G25	Pn	Qn
	110% of the nominal voltage	G20	G20	G25	Pn	Qn
	Wind conditions	G20	G20	G25	Pn	Qn

Test Gas & Interchangeability of Gases



DVGW-G260/I (T=273K, p=1,01325mbar)

Parameter		Unit	L	H
Wo,n	Range	MJ/m^3	37,8 … 46,8	46,1 … 56,5
	Nominal	MJ/m^3	44,6	54
	Local change	MJ/m^3	+2,16 / -4,32	+2,52 / -5,04
Ho,n	Range	MJ/m^3	30,2 … 47,2	
	Nominal	MJ/m^3	Not defined	
	Local change	MJ/m^3	Not defined	
D	Realitive density	-	0,55 … 0,70	
Pappliance	Range	Mbar	18 … 24	
	Nominal	Mbar	20	

- What happens to burner to different gas qualities?

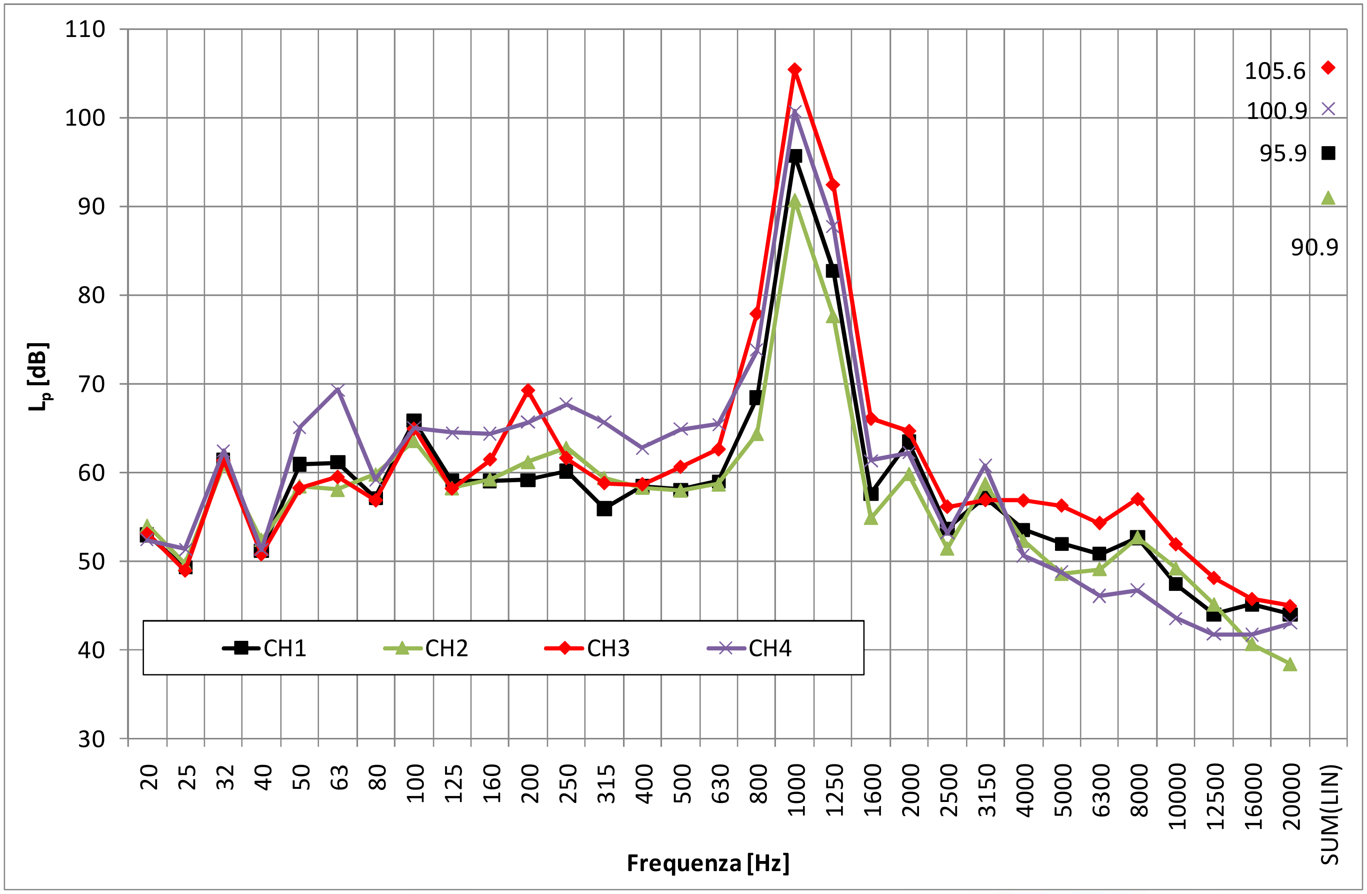
- One way: Wobbe Index: HV/sqrt (rel. density)
    - Many work done by AGA, AHRI on interchangeability – LNG

Example for input rate change

- Pressure: (no regulator)
- 20 mbar->24 mbar => +10%
- Wobbe:
- 54 MJ/m^3 ->56,5 MJ/m^3 => +5%

Design for Application – Noise

FFT analysis



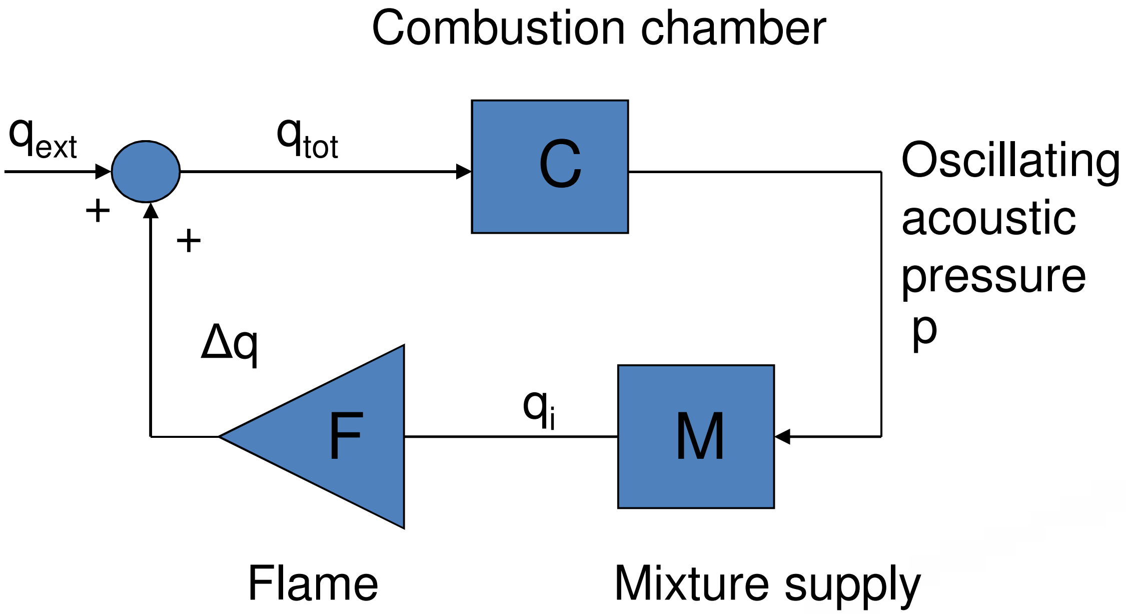
Design for Application – Noise

ASHRAE TC 6.10 (Fuels and Combustion) :

Validation of low-order acoustic model of boilers and its application for diagnosing combustion driven oscillations, Prof. David Herrin – University of Kentucky

Pressure – heat release oscillation

heat release proportional to acoustic velocity



q_i: volume velocity of the mixture flow

Δq: volume flow oscillation

q_{ext}:external perturbation to volume acoustic velocity

q_{tot}: $\Delta q + q_{ext}$

Feedback loop stability model: Baade, P. K., “Design Criteria and Models for Preventing Combustion Oscillations,” ASHRAE Transactions, Vol. 84, Part 1, pp. 449-465 (1978).

Bibliography

Jones H.R.N. , ***Domestic gas burner design*** , British Gas

Ozisik M. Necati , ***Heat transfer*** , McGrawHill

Ortolani Carlo , ***Combustione*** , Cittastudiedizioni

Gilioli M. , ***Studio parametrico di un sistema sperimentale a gas naturale per applicazioni domestiche*** , Università degli studi di Modena

Podeschi E. , ***Caratterizzazione vibro-acustica di caldaia a condensazione*** , Worgas Bruciatori