Energy in Action

Premix Combustion

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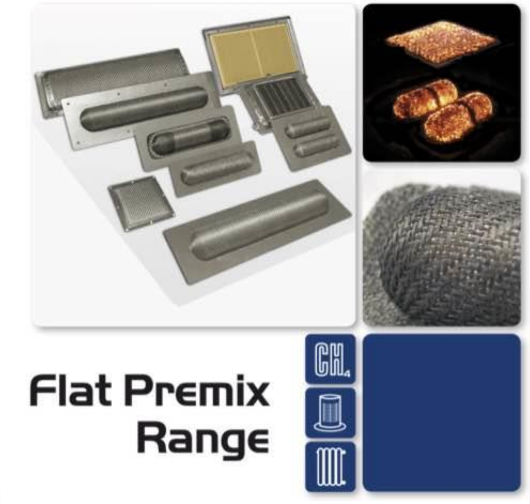
ENERGY TRANSFORMATION TECHNOLOGY

Outline

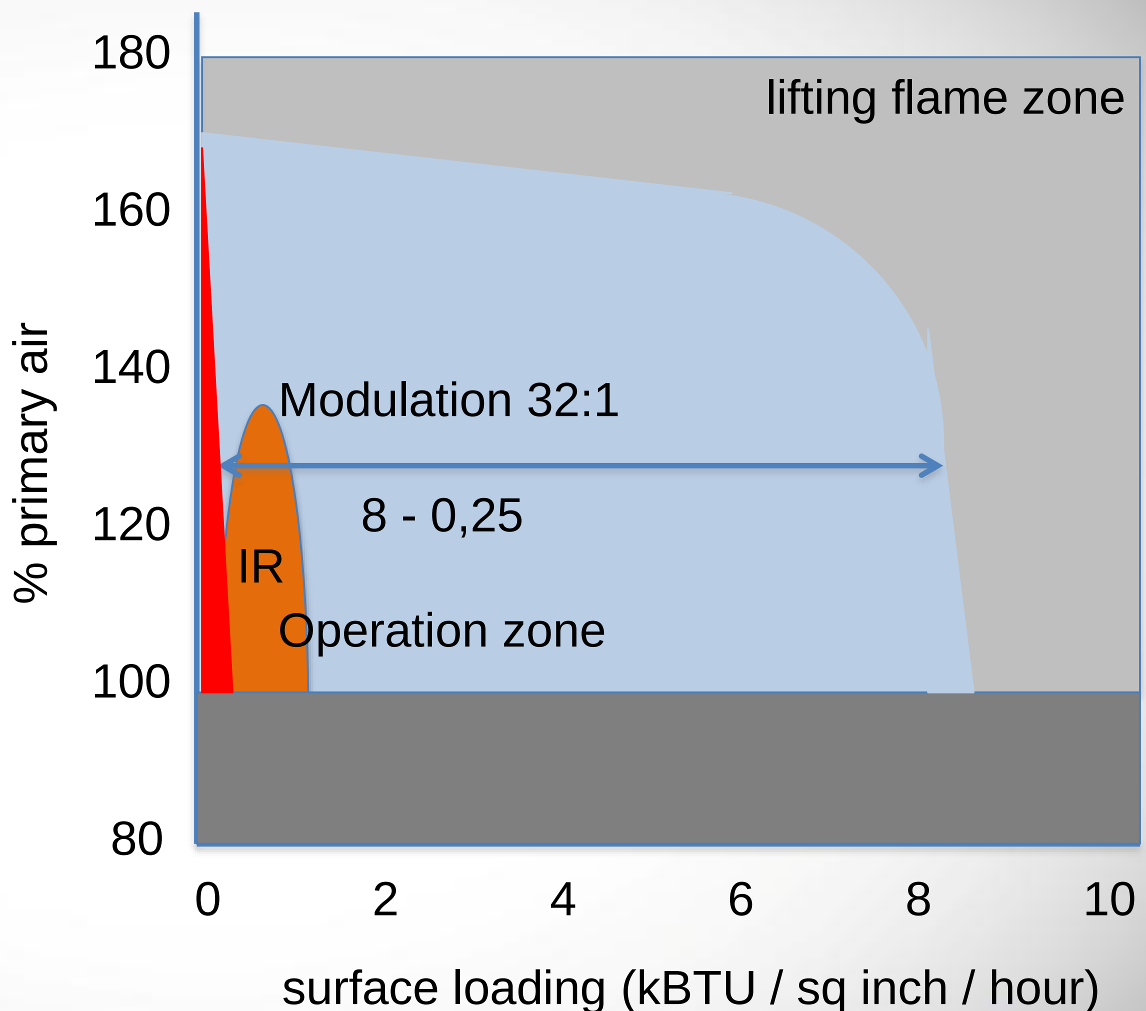
- Premix Burner – Definition
- Flame Stability
- Combustion Resonance
- Emissions

Premix Burner - Definition



Premix Burner - Definition

Parameter	Description
Air/fule ratio	>=100%
Input rate	Up to 60,000,000 BTU/h
Specific surface load	Up to 8 kBTU/(sq inch hour)
Flame lenght	< 2 inch
Material	Metal, metal fiber (woven, knitted and sintered), ceramic tiles, SiC porous, ceramic fiber woven
Lifetime	40,000 hours, 300,000 cycles
Surface tempertaure	800° F to 1900° F
Pressure drop	< 500 Pa , typical 200Pa



Flame stability– premix surface burner

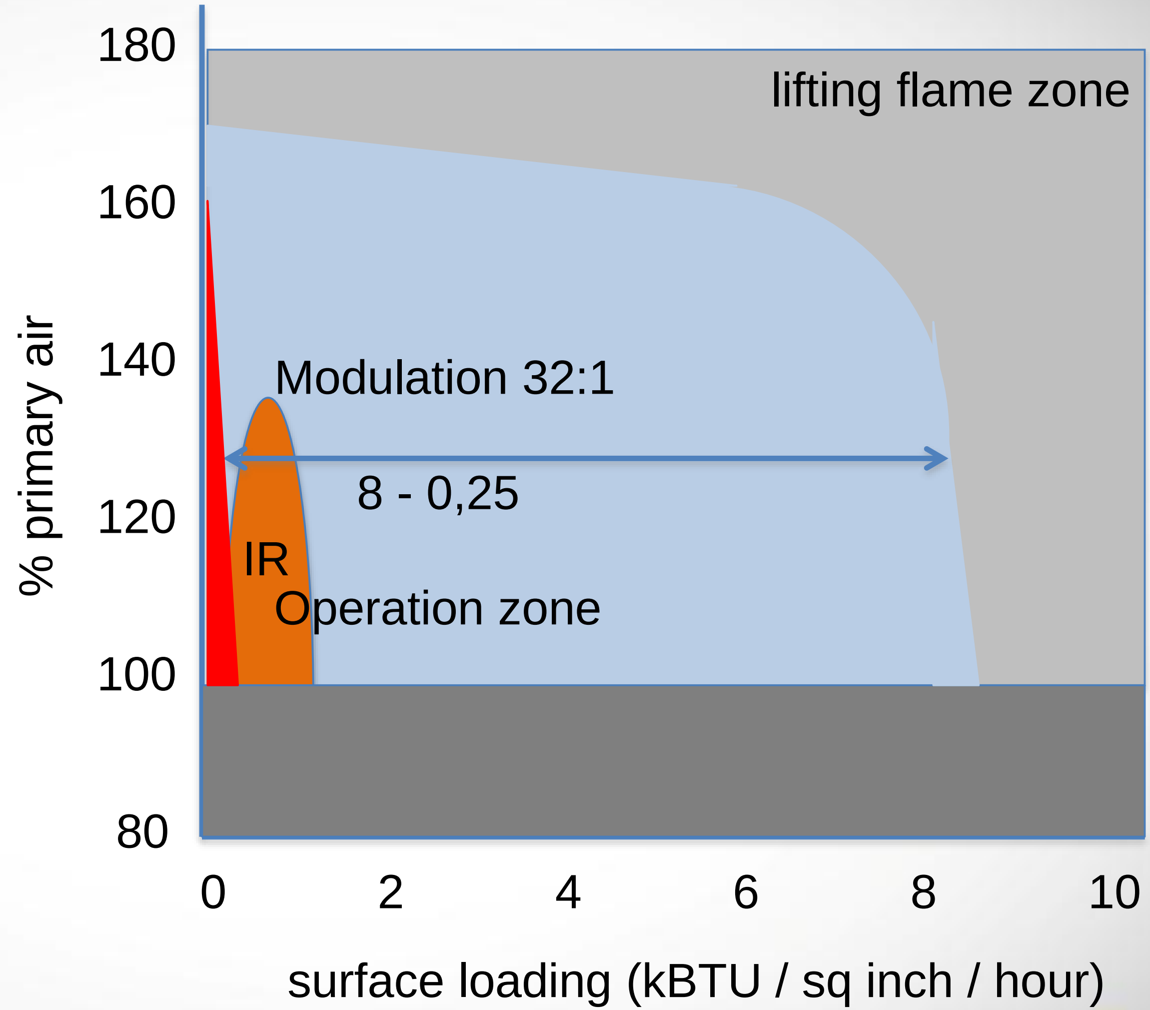
	Surface load	Primary air
Flash back	up	up
lifting	down	down

Flashback zone

- L/d <= 1 metal
  - L=thickness
  - D=hole diameter
- L/d > 1 metal mesh as flame arrestor or other high insulating material (ceramic)

Modulation: limitation is lift of and flashback (can be avoided by arrestor as metal fiber)

Below infra-red is blue!!!!



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Flame Stability - Ignition

3 conditions

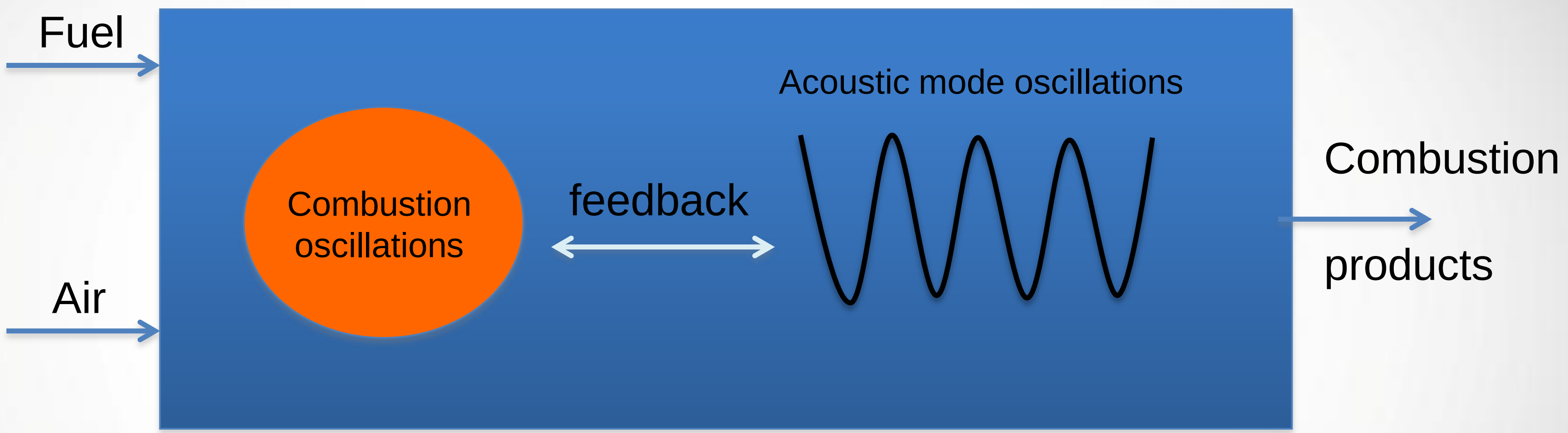
- Right gas air mixture in the flamable limit
- Sufficient energy to start reaction
- A certain volume has to have a temperature over ignition T

Why often ignition doesn’t occur ?

•No good mixture
•Mixture doesn’t reach / exit the burner where ignition source is located
•Negative pressure (burner) in zone of ignition electrode
•Distance of electrode to burner not around 6-10mm
•Humidity

Combustion Resonance- System

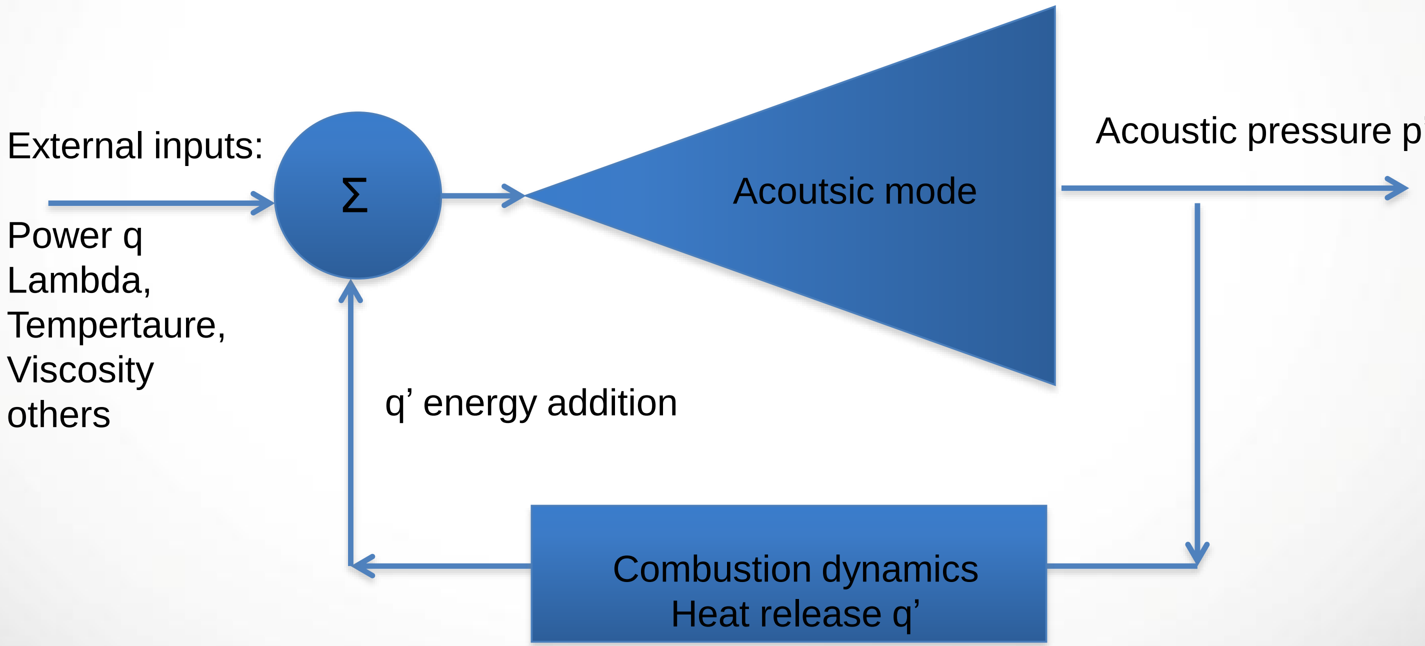
Cause of combustion resonance



System – Driving – Damping - Stability

Combustion Resonance- Driving

- Feedback between combustion and acoustic mode oscillations
- Time constants of combustion instabilities and acoustic frequency similar
- Phase shift between 0-90° or 270° -360°



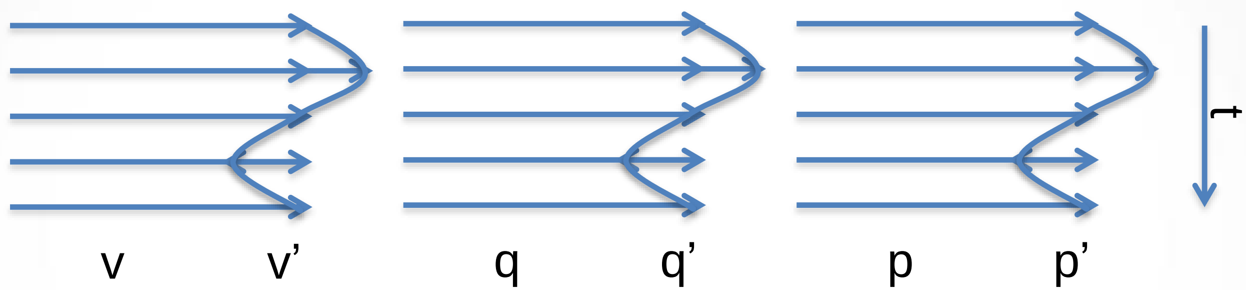
Combustion Resonance- Damping

- Out of phase, between 90° - 270° (q’, p’)
  - Passive control
    - **Lambda quarter tube**
  - Active control
    - fuel injection controlled electronically “out of phase” in a feedback loop
    - Add another wave “out of phase”
- Modify the transfer function of the burner (try to go out of resonance conditions)
  - **Cross sheet – break wave – create two or more different zones**
  - **Pressure drop**
  - **porting**
- Chimney length (change resonance frequency)
- Viscosity (strong temperature dependance)
- Heat transfer (out of acoustic mode)
- **Helmholz resonator**
- Acoustic radiation (absorption)

Combustion Resonance - Stability

Thermoacoustic instabilities : pressure oscillation p' coupled (feedback) with unsteady heat release q'

Any point in the boiler !!!!

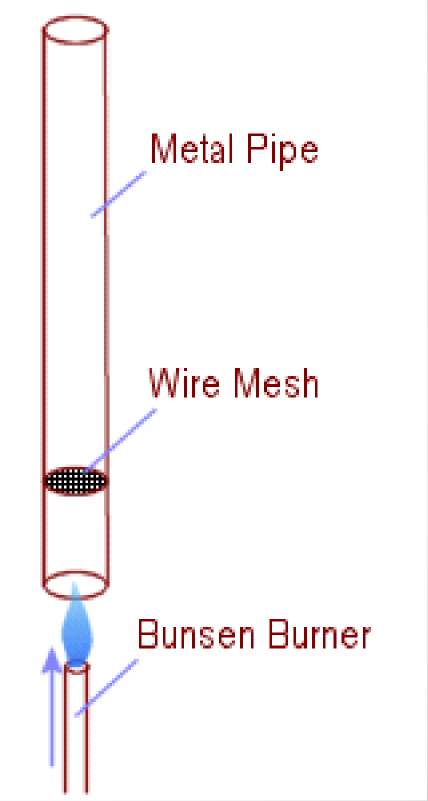


v = mean combustion gas mixture velocity
v' = standing sound wave velocity
q = mean heat release (power setting of boiler)
q' = additional/less heat release through acoustic wave per volume
p = mean combustion chamber pressure
p' = standing sound wave pressure

Combustion Resonance - Stability

Stability: **Rayleigh Criteria** at single point on burner surface

dE = energy change of accoustic mode
γ = adiabatic gas constant (cp/cv)
p0 = ambient gas pressure

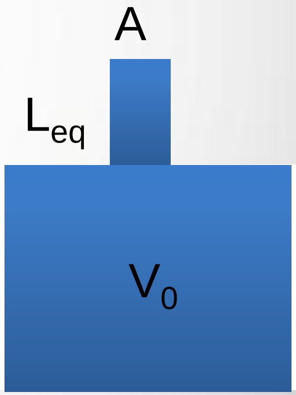


$$dE = \frac{\gamma - 1}{p_0 \, \gamma} \int_V dv \int_t^{t+T} p' q' dt$$

Combustion Resonance – Helmholtz Resonator

- Helmholtz resonator is an air resonance in a cavity . We all know the phenomena from an empty bottle where blowing air across the top. In our analogy of a combustion system the air blowing across are our acoustic mode oscillation.

- The damping is casued by the absorption of acoustic mode into the cavity.



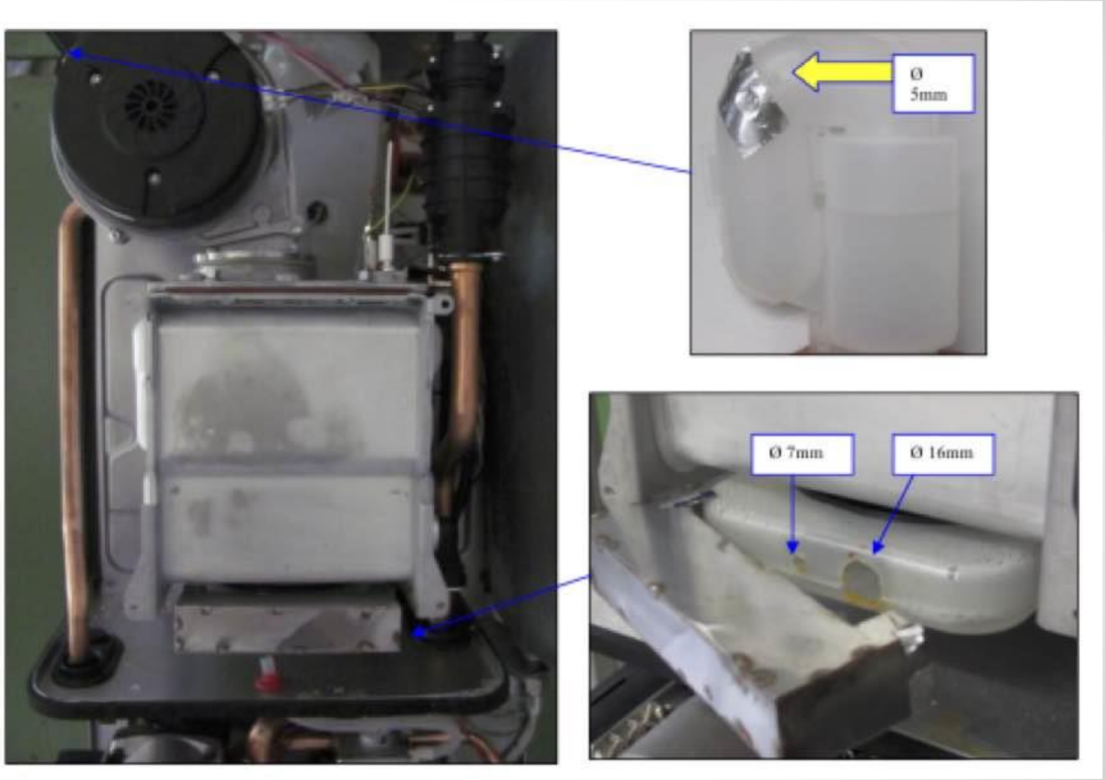
- *f* resonance frquency Hz
- *v* speed of sound in a gas (m/s)
- *A* cross sectional area in neck
- V_0 static volume of the cavity
- L_{eq} equivalent length of the neck

$$f = \frac{v}{2\pi}\sqrt{\frac{A}{V_0 L_{eq}}}$$

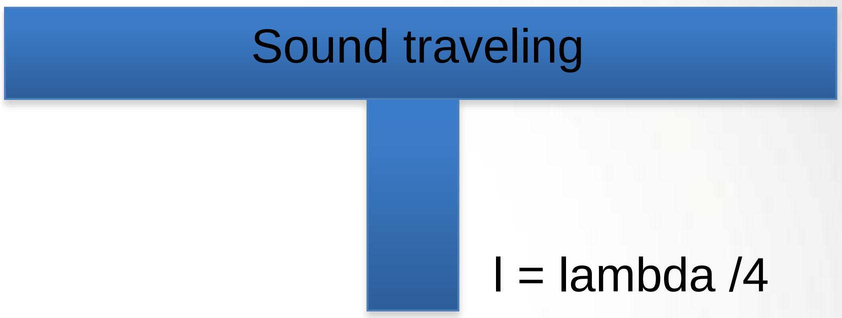
Combustion Resonance – Helmholtz Resonator

Practical application

- condensate path
- air intake path
- combustion chamber



Combustion Resonance – lambda quarter tube



Practical application

-air intake path “snorkel”

-How it works?

- Lambda quarter creates a lambda / 2 shift with negative feedback on sound

Emission

$CH_4 + O_2 \rightarrow CO_2 + CO + H_2O$

$N_2 + 0_2 \rightarrow NO_x$

CO formation

- Cold flame
- Insufficient air
- Flame impingment

NO_X formation

- Thermal NO_X
- Prompt NO_X

Premix technology today in the < 10 ppm range

- NOx reduction techniques
  - Lower flame tempertaure and separation of O_2 , N_2 at high temperature
  - high lambda, radiation, cooling, residence time, flue gas recirculation, water spray

SQAMD - Furnace

Rule 1111: Furnace

- Reduction of NOx emissions from natural gas fired fan type central furnaces
- < 175,000 BTU/hour for heating
- < 65,000 BTU/hour for combination heating and cooling

Compliance date	Equipment category	Nox emission limts (nanograms/Joule)
October 1, 2012	**Mobile home funace**	**40**
April 1, 2015	**Condensing furnace**	**14**
October 1, 2015	**Non-condensing furnace**	**14**
October 1, 2016	Weatherrized furnace	14
October 1, 2018	Mobile home firnace	14

SCAQMD – Water Heaters

Rule 1121

- Control of nitrogen oxydes from residential type, natural gas-fired water heaters
- < 75,000 BTU/hour

Compliance date	Equipment category	Nox emission limts (nanograms/Joule)
January 1, 2000	**Gas fired mobile home water heaters**	**40**
Until July 1, 2002	Gas fired water heater	40
July 1, 2002	**Gas fired water heater**	**20**
January 1, 2006	**Gas fired water heater less than or equal 50 gallon capacity Excluding direct-vent,power-vent,power direct-vent water heaters**	10
January 1, 2007	**Gas fired water heater larger than 50 gallons capacity, Excluding direct-vent,power-vent,power direct-vent water heaters**	**10**

SCAQMD – small Boiler

Rule 1146.2

- Emissions of oxides of nitrogen from large water heaters and small boilers and process heaters
- <= 2million BTU/hour

Compliance date	Equipment category	Nox emission limts (ppm)
January 1, 2000	Type 2 – small boilers or large sized process heaters, < 2 million BTU/h	30
January 1, 2001	Type 1 – large water heater or smaller sized process heaters , < 2 million BTU/h	55
January 1, 20110	**Type 2**	**20**
January 1, 2012	**Type 1**	**20**

SCAQMD – medium Boiler

Rule 1146.1

- Emissions of oxides of nitrogen from small industrial, institutional, and commercial boilers, steam generators, and process heaters
- > 2 million BTU/hour and < 5 million BTU/hour

Compliance date	Equipment category	Nox emission limts (ppm)
January 1, 2015	Any units fired on landfill gas	25
January 1, 2015	Any units fired on digester gas	15
January 1, 2014	Atmospheric units	12
January 1, 2012	Any unit fired on NG, excluding units located at schools and universities, atmospheric units, and thermal fluid heaters	9
January 1, 2014	Any unit fired on NG located at schools and univeristies, excluding atmospheric units, and thermal fluid heaters	9

SCAQMD – large Boiler

Rule 1146

- Emissions of oxides of nitrogen from industrial , institutional, and commercial boilers, steam generators, and process heaters
- >5 million BTU/hour

Compliance date	Equipment category	Nox emission limts (ppm)
September 5, 2008	All units fired on gaseous fuels	30
September 5, 2008	**Any units fired on landfill gas**	**25**
January 1, 2015	**Any units fired on digester gas**	**15**
January 1, 2013	**Group 1: unit burning NG >75 million BTU/h, excluding thermal fluid heaters**	**5**
January 1, 2014	**Group 2: units burning gaseous fuels, excluding digester and landfill gases, and thermal fluid heaters < 75 million BTU/h and >=20 million BTU/h**	**9**
January 1, 2015	**Group 3: units burning gaseous fuels, excluding digester and landfill gases, and thermal fluid heaters < 20 million BTU/h and >=5 million BTU/h**	**9**

SCAQMD – commercial food ovens

Rule 1153.1

- Emission of oxides of nitrogen from commercial food ovens
- Ovens, dryers, smokers, dry roasters

Compliance date	Equipment category	Nox (ppm)@3% 02	CO (ppm) @3 % O2
September 5, 2008	Process tempertaure <= 500˚ F	40	800
September 5, 2008	Process tempertaure > 500˚ F	60	800

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Thank you for your attention

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