Combustion and Air Pollution Control Modifications for Compliance and Efficiency

The ChemShow NYC

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TMTS

COMBUSTION BASICS

- **Fuel properties**
- **Combustion calculations**
- **Air/fuel ratio and excess air**
- **Flame temperatures**
- **Applications**

Combustion…

Is a rapid combination of oxygen and fuel that results in the release of heat

Fuel, air and an ignition source are key requirements for combustion to occur

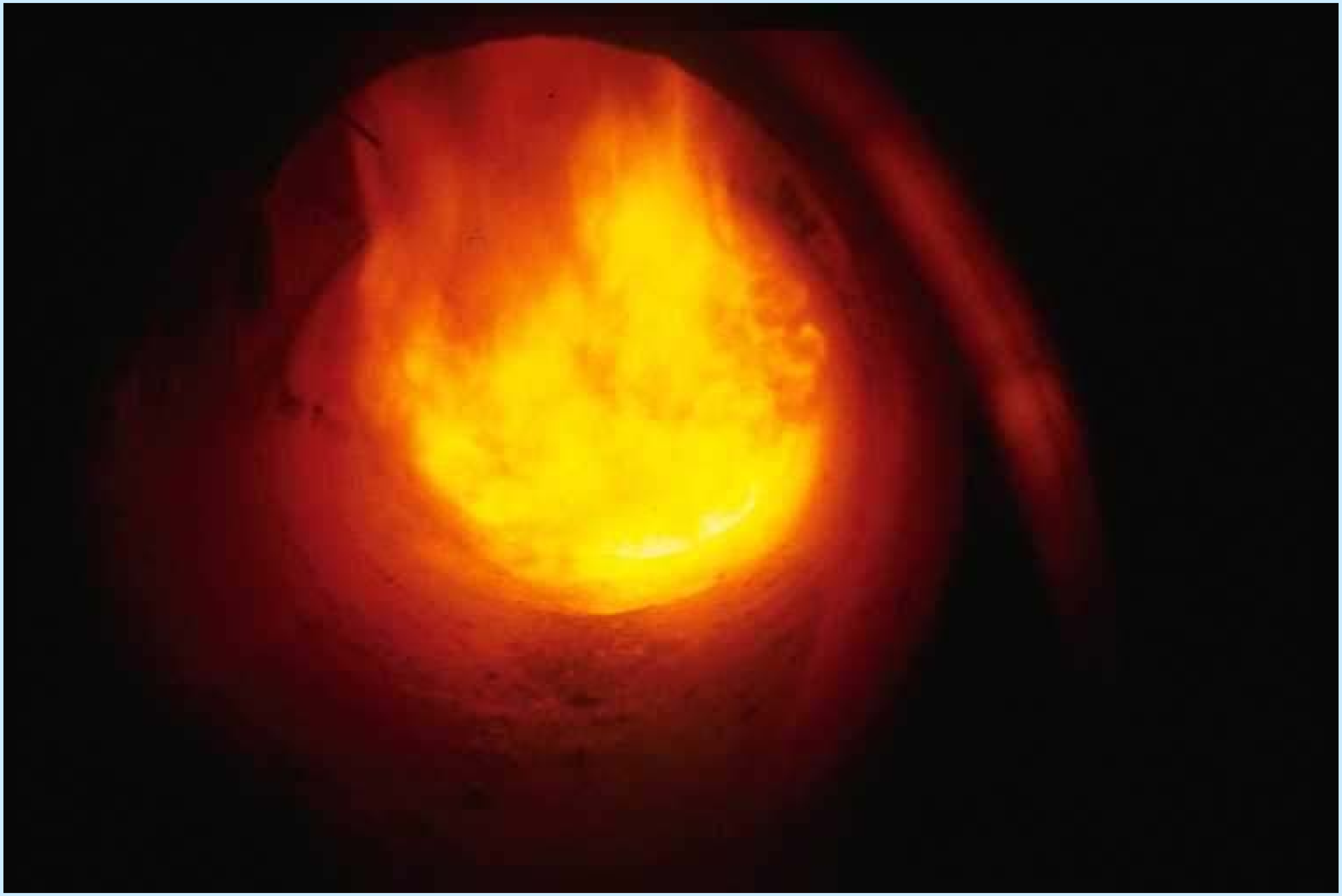
The Three T's

Always keep in mind the 3 T's of combustion:

- **Time**
- **Temperature**
- **Turbulence**

If all three exist in adequate amounts, plus the right amount of oxygen, good combustion will occur

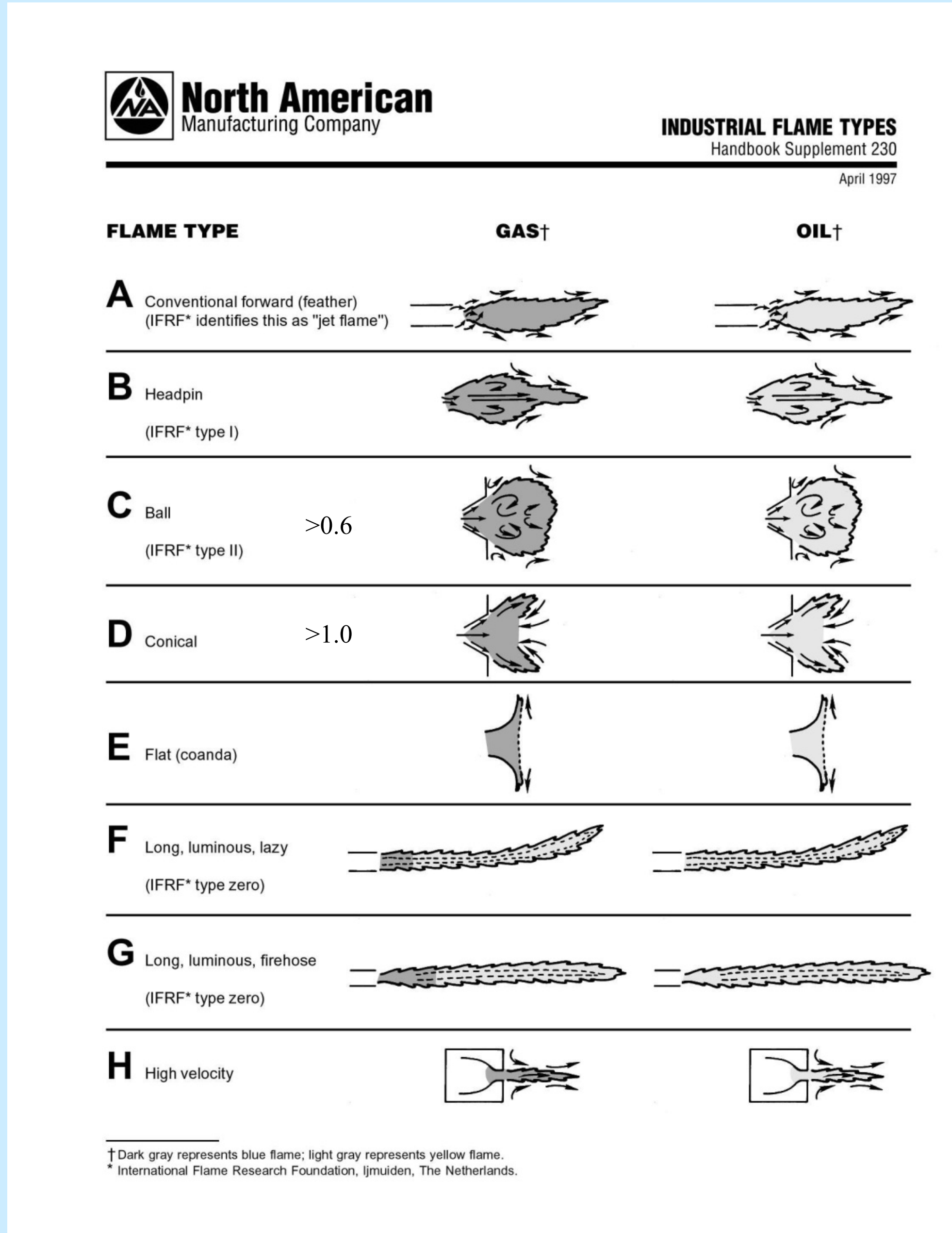
Flame from Batch Kiln Test



Burner Flame Types

There are no bad burners – but they can be misapplied, and be the wrong burner for a particular end use

Burners have the means to mix fuel and air, a point of attachment, and source of ignition



Products of Combustion

- The two fundamental products of the reaction are CO_2 and H_2O
- N_2, and O_2 vary with excess air level
- Other products may include, SO_2, SO_3, NOx, HCl, HF, HBr and others, depending on the composition of the fuel and level of oxygen

Shortcuts and Rules of Thumb

Conversion of moles to volume:

1 lb mole of any gas = 378.7 scf at standard conditions
(60 ºF and 14.7 psia)

To find gas density: 1 mole of methane weighs 16 lb
So the density of methane = 16 / 378.7 = 0.042 lb/scf

Shortcuts and Rules of Thumb

For combustion air volume:
1+(XS air%/100) x (Btu / hr input)] / 6,000 = scfm combustion air

where factor (1 + XS air/100) is 1.0 at 0% XS air, and 2.0 at 100% XS air

For combustion air mass:
1+(XS air%/100) x 765 is lb air required to burn 1 MM Btu of fuel

Example:

A 10 MM Btu/hr burner running at 50% XS air requires:

[(1 + 50/100) x (10,000,000)] / 6,000 = 2505 scfm air

or

10 x (1 + 50/100) x 765 = 11,475 lb/hr air

Table 1 Combustion Constants

No. Substance	Formula	Molecular Weight[a]	Lb per Cu Ft[b]	Cu Ft per Lb[b]	Sp Gr Air = 1.000[b]	Heat of Combustion[c]: Btu per Cu Ft Gross	Btu per Cu Ft Net[d]	Btu per Lb Gross	Btu per Lb Net[d]	Cu Ft per Cu Ft of Combustible: Required for Combustion O_2	N_2	Air	Flue Products CO_2	H_2O	N_2	Lb per Lb of Combustible: Required for Combustion O_2	N_2	Air	Flue Products CO_2	H_2O	N_2	Experimental Error in Heat of Combustion Percent + or −
1 Carbon	C	12.01	—	—	—	—	—	14,093[g]	14,093[g]	—	—	—	—	—	—	2.664	8.863	11.527	3.664	—	8.863	0.012
2 Hydrogen	H_2	2.016	0.005327	187.723	0.06959	325.0	275.0	61,100	51,623	0.5	1.882	2.382	—	1.0	1.882	7.937	26.407	34.344	—	8.937	26.407	0.015
3 Oxygen	O_2	32.000	0.08461	11.819	1.1053	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
4 Nitrogen (atm)	N_2	28.016	0.07439[e]	13.443[e]	0.9718[e]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
5 Carbon monoxide	CO	28.01	0.07404	13.506	0.9672	321.8	321.8	4,347	4,347	0.5	1.882	2.382	1.0	—	1.882	0.571	1.900	2.471	1.571	—	1.900	0.045
6 Carbon dioxide	CO_2	44.01	0.1170	8.548	1.5282	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
Paraffin series C_nH_{2n+2}																						
7 Methane	CH_4	16.041	0.04243	23.565	0.5543	1013.2	913.1	23,879	21,520	2.0	7.528	9.528	1.0	2.0	7.528	3.990	13.275	17.265	2.744	2.246	13.275	0.033
8 Ethane	C_2H_6	30.067	0.08029[e]	12.455[e]	1.04882[e]	1792	1641	22,320	20,432	3.5	13.175	16.675	2.0	3.0	13.175	3.725	12.394	16.119	2.927	1.798	12.394	0.030
9 Propane	C_3H_8	44.092	0.1196[e]	8.365[e]	1.5617[e]	2590	2385	21,661	19,944	5.0	18.821	23.821	3.0	4.0	18.821	3.629	12.074	15.703	2.994	1.634	12.074	0.023
10 n-Butane	C_4H_{10}	58.118	0.1582[e]	6.321[e]	2.06654[e]	3370	3113	21,308	19,680	6.5	24.467	30.967	4.0	5.0	24.467	3.579	11.908	15.487	3.029	1.550	11.908	0.022
11 Isobutane	C_4H_{10}	58.118	0.1582[e]	6.321[e]	2.06654[e]	3363	3105	21,257	19,629	6.5	24.467	30.967	4.0	5.0	24.467	3.579	11.908	15.487	3.029	1.550	11.908	0.019
12 n-Pentane	C_5H_{12}	72.144	0.1904[e]	5.252[e]	2.4872[e]	4016	3709	21,091	19,517	8.0	30.114	38.114	5.0	6.0	30.114	3.548	11.805	15.353	3.050	1.498	11.805	0.025
13 Isopentane	C_5H_{12}	72.144	0.1904[e]	5.252[e]	2.4872[e]	4008	3716	21,052	19,478	8.0	30.114	38.114	5.0	6.0	30.114	3.548	11.805	15.353	3.050	1.498	11.805	0.071
14 Neopentane	C_5H_{12}	72.144	0.1904[e]	5.252[e]	2.4872[e]	3993	3693	20,970	19,396	8.0	30.114	38.114	5.0	6.0	30.114	3.548	11.805	15.353	3.050	1.498	11.805	0.11
15 n-Hexane	C_6H_{14}	86.169	0.2274[e]	4.398[e]	2.9704[e]	4762	4412	20,940	19,403	9.5	35.760	45.260	6.0	7.0	35.760	3.528	11.738	15.266	3.064	1.464	11.738	0.05
Olefin series C_nH_{2n}																						
16 Ethylene	C_2H_4	28.051	0.07456	13.412	0.9740	1613.8	1513.2	21,644	20,295	3.0	11.293	14.293	2.0	2.0	11.293	3.422	11.385	14.807	3.138	1.285	11.385	0.021
17 Propylene	C_3H_6	42.077	0.1110[e]	9.007[e]	1.4504[e]	2336	2186	21,041	19,691	4.5	16.939	21.439	3.0	3.0	16.939	3.422	11.385	14.807	3.138	1.285	11.385	0.031
18 n-Butene (Butylene)	C_4H_8	56.102	0.1480[e]	6.756[e]	1.9336[e]	3084	2885	20,840	19,496	6.0	22.585	28.585	4.0	4.0	22.585	3.422	11.385	14.807	3.138	1.285	11.385	0.031
19 Isobutene	C_4H_8	56.102	0.1480[e]	6.756[e]	1.9336[e]	3068	2869	20,730	19,382	6.0	22.585	28.585	4.0	4.0	22.585	3.422	11.385	14.807	3.138	1.285	11.385	0.031
20 n-Pentene	C_5H_{10}	70.128	0.1852[e]	5.400[e]	2.4190[e]	3836	3586	20,712	19,363	7.5	28.232	35.732	5.0	5.0	28.232	3.422	11.385	14.807	3.138	1.285	11.385	0.037
Aromatic series C_nH_{2n-6}																						
21 Benzene	C_6H_6	78.107	0.2060[e]	4.852[e]	2.6920[e]	3751	3601	18,210	17,480	7.5	28.232	35.732	6.0	3.0	28.232	3.073	10.224	13.297	3.381	0.692	10.224	0.12
22 Toluene	C_7H_8	92.132	0.2431[e]	4.113[e]	3.1760[e]	4484	4284	18,440	17,620	9.0	33.878	42.878	7.0	4.0	33.878	3.126	10.401	13.527	3.344	0.782	10.401	0.21
23 Xylene	C_8H_{10}	106.158	0.2803[e]	3.567[e]	3.6618[e]	5230	4980	18,650	17,760	10.5	39.524	50.024	8.0	5.0	39.524	3.165	10.530	13.695	3.317	0.849	10.530	0.36
Miscellaneous gases																						
24 Acetylene	C_2H_2	26.036	0.06971	14.344	0.9107	1499	1448	21,500	20,776	2.5	9.411	11.911	2.0	1.0	9.411	3.073	10.224	13.297	3.381	0.692	10.224	0.16
25 Naphthalene	$C_{10}H_8$	128.162	0.3384[e]	2.955[e]	4.4208[e]	5854[f]	5654[f]	17,298[f]	16,708[f]	12.0	45.170	57.170	10.0	4.0	45.170	2.996	9.968	12.964	3.434	0.562	9.968	—[f]
26 Methyl alcohol	CH_3OH	32.041	0.0846[e]	11.820[e]	1.1052[e]	867.9	768.0	10,259	9,078	1.5	5.646	7.146	1.0	2.0	5.646	1.498	4.984	6.482	1.374	1.125	4.984	0.027
27 Ethyl alcohol	C_2H_5OH	46.067	0.1216[e]	8.221[e]	1.5890[e]	1600.3	1450.5	13,161	11,929	3.0	11.293	14.293	2.0	3.0	11.293	2.084	6.934	9.018	1.922	1.170	6.934	0.030
28 Ammonia	NH_3	17.031	0.0456[e]	21.914[e]	0.5961[e]	441.1	365.1	9,668	8,001	0.75	2.823	3.573	—	1.5	3.323	1.409	4.688	6.097	—	1.587	5.511	0.088
29 Sulfur	S	32.06	—	—	—	—	—	3,983	3,983	—	—	—	—	—	—	0.998	3.287	4.285	SO_2 1.998	—	3.287	0.071
30 Hydrogen sulfide	H_2S	34.076	0.09109[e]	10.979[e]	1.1898[e]	647	596	7,100	6,545	1.5	5.646	7.146	SO_2 1.0	1.0	5.646	1.409	4.688	6.097	SO_2 1.880	0.529	4.688	0.30
31 Sulfur dioxide	SO_2	64.06	0.1733	5.770	2.264	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
32 Water vapor	H_2O	18.016	0.04758[e]	21.017[e]	0.6215[e]	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—
33 Air	—	28.9	0.07655	13.063	1.0000	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—	—

All gas volumes corrected to 60F and 30 in. Hg dry. For gases saturated with water at 60F, 1.73% of the Btu value must be deducted.

[a] Calculated from atomic weights given in "Journal of the American Chemical Society", February 1937.

[b] Densities calculated from values given in grams per liter at 0C and 760 mm in the International Critical Tables allowing for the known deviations from the gas laws. Where the coefficient of expansion was not available, the assumed value was taken as 0.0037 per °C. Compare this with 0.003662 which is the coefficient for a perfect gas. Where no densities were available the volume of the mol was taken as 22.4115 liters.

[c] Converted to mean Btu per lb (1/180 of the heat per lb of water from 32F to 212F) from data by Frederick D. Rossini, National Bureau of Standards, letter of April 10, 1937, except as noted.

[d] Deduction from gross to net heating value determined by deducting 18,919 Btu per pound mol of water in the products of combustion. Osborne, Stimson, and Ginnings, "Mechanical Engineering", p. 163, March 1935, and Osborne, Stimson, and Fiock, National Bureau of Standards Research Paper 209.

[e] Denotes that either the density or the coefficient of expansion has been assumed. Some of the materials cannot exist as gases at 60F and 30 in. Hg pressure, in which case the values are theoretical ones given for ease of calculation of gas problems. Under the actual concentrations in which these materials are present their partial pressure is low enough to keep them as gases.

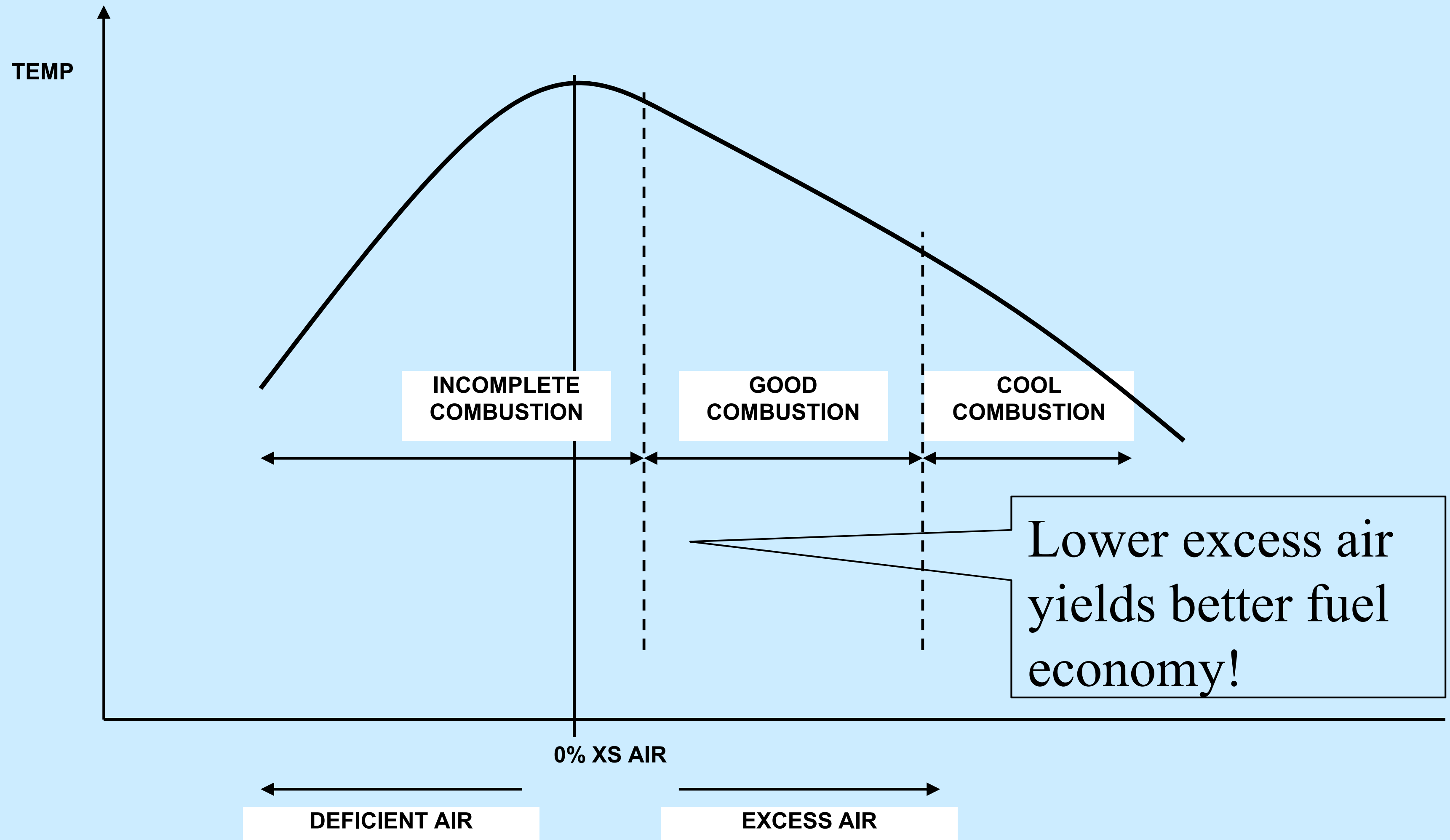
[f] From Third Edition of "Combustion."

[g] National Bureau of Standards, RP 1141.

Reprinted from "Fuel Flue Gases", 1941 Edition, courtesy of American Gas Association.

Source: B&W Steam Book

Temperature vs. Air to Fuel Ratio



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Combustion Temperature

Temperature:

- **Indicator of combustion stability**
- **Stable conditions exist when the temperature is in the flammability range (> 2300 F) as approximately defined by the Lower and Upper explosive Limits**

Adiabatic Flame Temperature

(at zero % heat loss)

$Q = M \times C_p \times$ temperature difference, or

Temperature difference = $Q / (M \times C_p)$

Where Q = Btu

M = Mass, lb of combustion products

C_p = Specific heat of combustion products, Btu/lb-F

1 mole CH_4, 16 lb X <u>LHV</u> 21,520 Btu / lb = Q = 344,320 Btu

At 100% XS air M = 565 lb for products of combustion

Temperature difference = 344,320 / (565 lb X 0.282) = 2,161ºF

where 0.282 is approximate integrated heat capacity at this temp

With 60ºF base temperature at standard conditions:

AFT = 60 + temperature difference = 60 + 2,161 = 2,221ºF

How to Estimate Temperatures

Refractories and alloys have a characteristic color

(Ref: Marks ME Handbook, based on emissivity of iron and steel)

Color	**Temp, F**
Dark red	1050
Dark cherry red	1175
Cherry red	1375
Orange	1650
Light orange	1725
Yellow	1825
White	2200

Too hot to keep fingers on steel, >120F

Radiant heat noticeable/uncomfortable on skin, >400F

Example Heat and Mass Balance

HEAT AND MASS BALANCE FOR THERMAL PROCESSING

By: Tom McGowan, TMTS Associates, Inc.
Filename: HTMSFMST
Date: 16-Apr-05
For:
Overview: Cocurrent kiln process
Excess air (XCS) includes leakage air.
All flow values (mass or volume) are per hour basis.
No POHC used for sizing maximum SCC burner capacity.
Propane gas is auxiliary fuel, baghouse after SCC for APC.

Major parameters entered in this line for excess air, primary and after burner temperatures

Major Parameters:

Primary Burner XCS	SCC XCS	POHC XCS	Prim. Temp	SCC Temp	Quench/Bag House Temp	Solids Chrg, lb/hr	Feed Moisture	Primary Radiatn Loss	Wet Wgt POHC
50%	25%	90%	1600	2000	400	40000	10.00%	5.00%	7.00%
		Ash temp	-150	F over gas temp			SCC Rad L	2.50%	

Stage 1, Primary Kiln Burner

Item	lb/hr	HHV MMBtuh	LHV MMBtuh	Sensible Heat MMBtuh	Flame Temp	Fuel Balance % Diff.
Auxiliary fuel	800	17.22	15.82			-0.09%
Air	18844					
Total	19644	17.22	15.82	15.82	3021	

Stage 2, Solids Injected in Primary Furnace

Item	lb/hr	HHV MMBtuh	LHV MMBtuh	Sensible Heat MMBtuh
Solids	33200			13.84
Moisture	4000		-4.24	3.08
POHC	2800	56.00	50.40	1.21
Air	76342			33.08
Total	116342	56.00	46.16	51.21

Calculations carry data from stage to stage for heat and mass

Example Heat and Mass Balance

Primary Chamber Outlet Gas Stream Plus Clean Ash

Item	lb/hr	HHV MMBtuh	LHV MMBtuh	Sensible Heat MMBtuh
Total gas	102786			44.53
Total solids	33200			13.84
Rad. loss			-3.66	
Total input			58.32	58.38

Stage 3, Primary Chamber Outlet Gas Stream

Item	lb/hr	Sensible Heat MMBtuh	SCC Inlet Gas temp	XCS air or O2, dry
Total gas	102786			
Solids		0.00		80%
Total	102786	44.53	1600	9.4%

Page 2, Heat and Mass Balance for Hazardous Waste Incineration

Stage 4, Secondary Combustion Chamber

Item	lb/hr	HHV MMBtuh	LHV MMBtuh	Sensible Heat MMBtuh	Flame Temp	Scfm	Acfm	Fuel Balance % Diff.
Total inlet gas	102786		44.53					
Auxiliary fuel	2000	43.05	39.55					
POHC in SCC	0	0.00	0.00					-0.89%
Air	39258							
Rad. loss			-2.91					
Total	144043			81.91	3331	30356	143606	
Total, stage 1-3+4			81.18					

Flows are calculated too for sizing fans and ducts

Oxygen/excess air calculated also

COMBUSTION SAFETY

We want fuel to burn…

when and where we want it to…

and not at other times…

or other places!

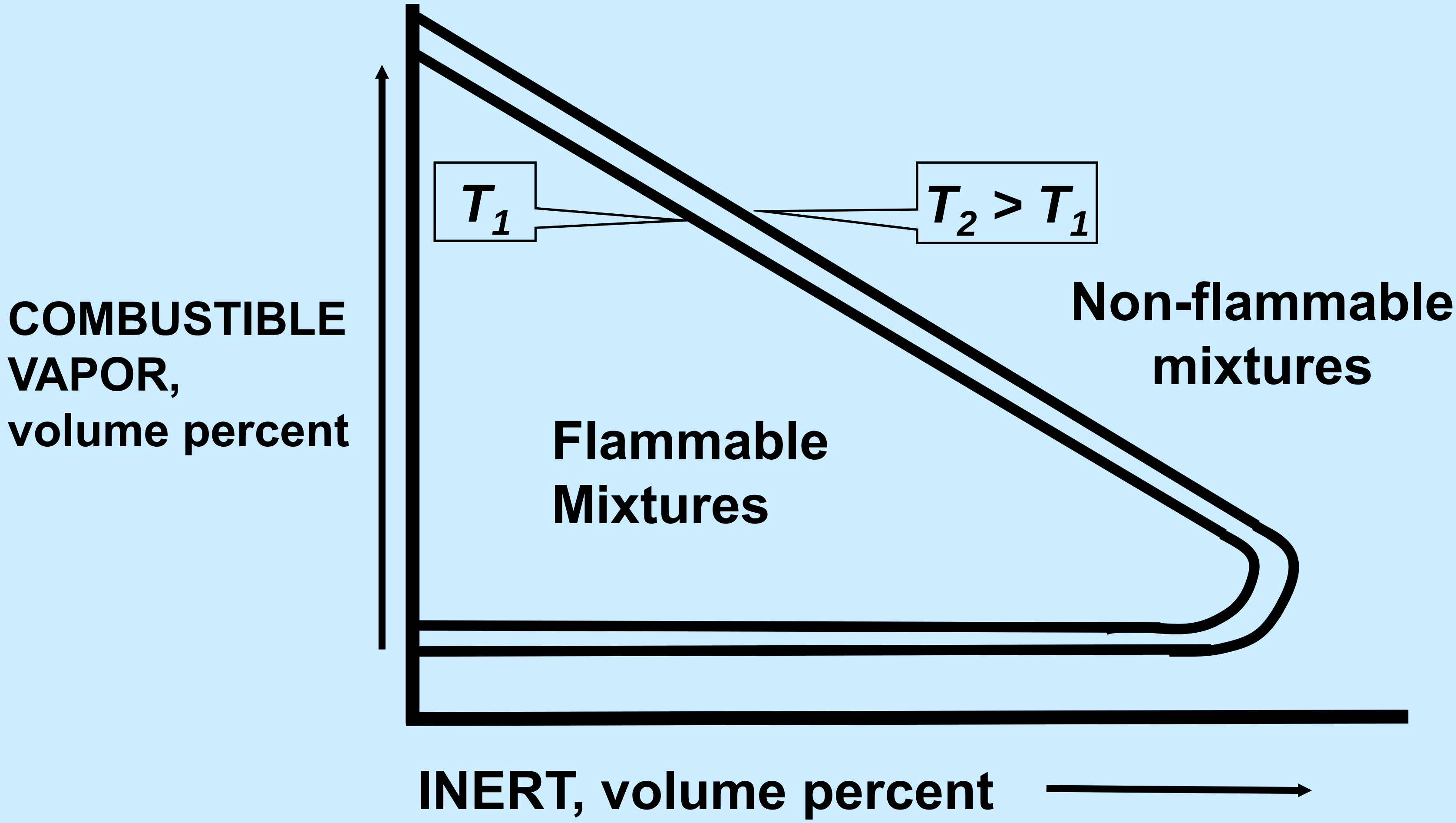
COMBUSTION SAFETY

Combustion system safety design elements:

- **BMS/Burner Management System/High temp limit**
- **Safety shut off valves, pressures switches (fuel trains)**
- **Prepurge (> 4 furnace volumes)**
- **Pilot trial for ignition (not to exceed 15 seconds)**
- **Fire eyes to monitor flame**
- **Start burner at low fire**

Limits of Flammability vs. Inert Percent in Air

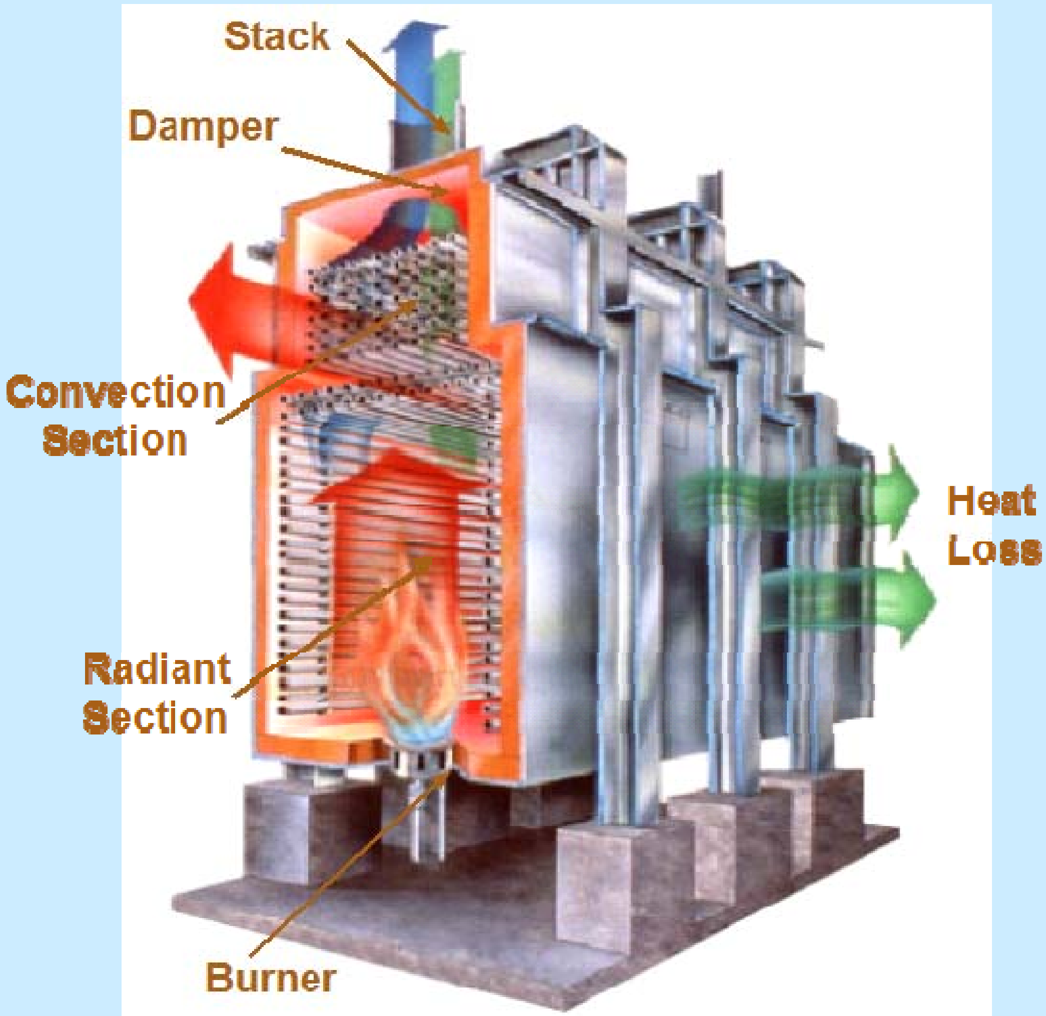
% Air = 100% - % Combustible Vapor - % Inert



Combustion Applications

Refinery Furnaces – Heaters - Reformers

Refinery Heater Cross-section



Heater Burners & Pipe Rack

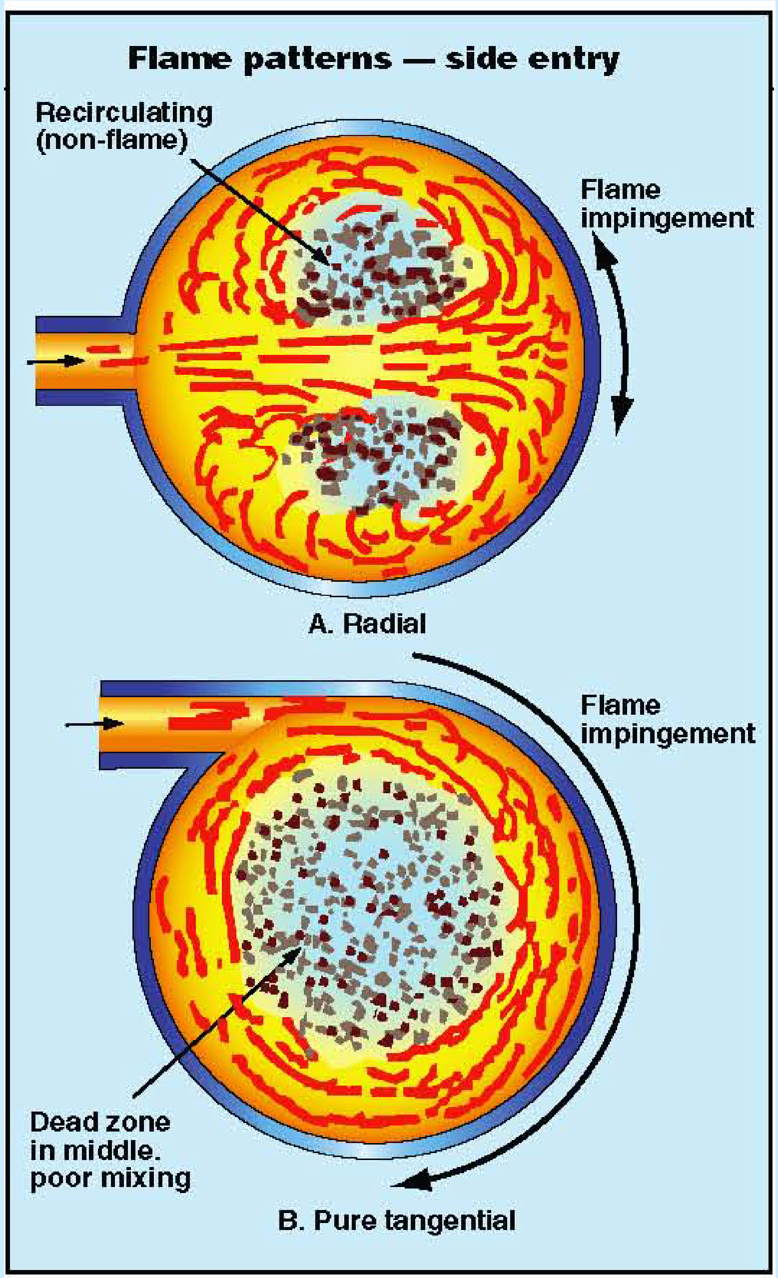
Courtesy John Zink

Steel Mill Arc Furnace Produces CO –

Application Requiring a Direct Thermal Oxidizer

Direct Thermal Oxidizer with 4 Auxiliary Burners

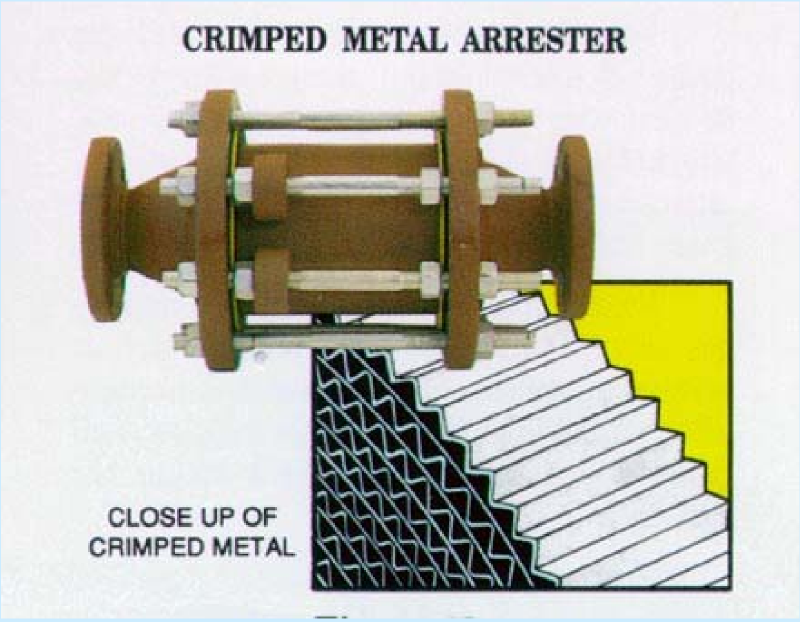
Oxidizer Fluid Dynamics – Mixing of waste Gas and Flame

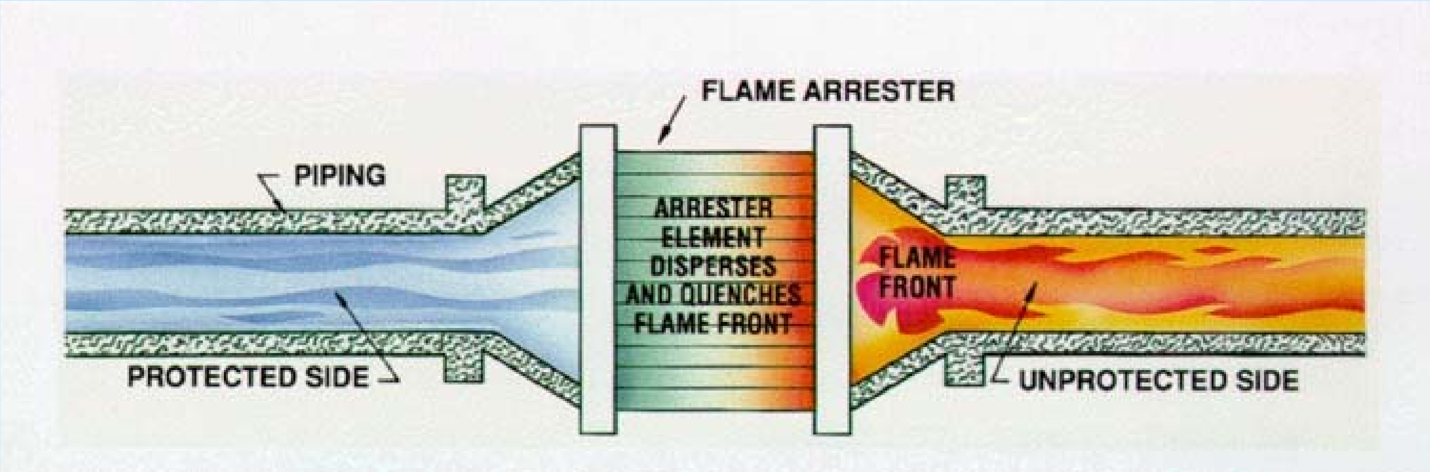


Safety Options for Oxidizers

- Liquid seal tanks used for flares
- Flame arrestors
- LOC (limiting oxygen concentration approach) per NFPA 69 and NFPA 86, to prevent ignition by running rich
- Less than 25% LEL, or up to 50% LEL via upgraded controls

Crimped Metal Flame Arrestor

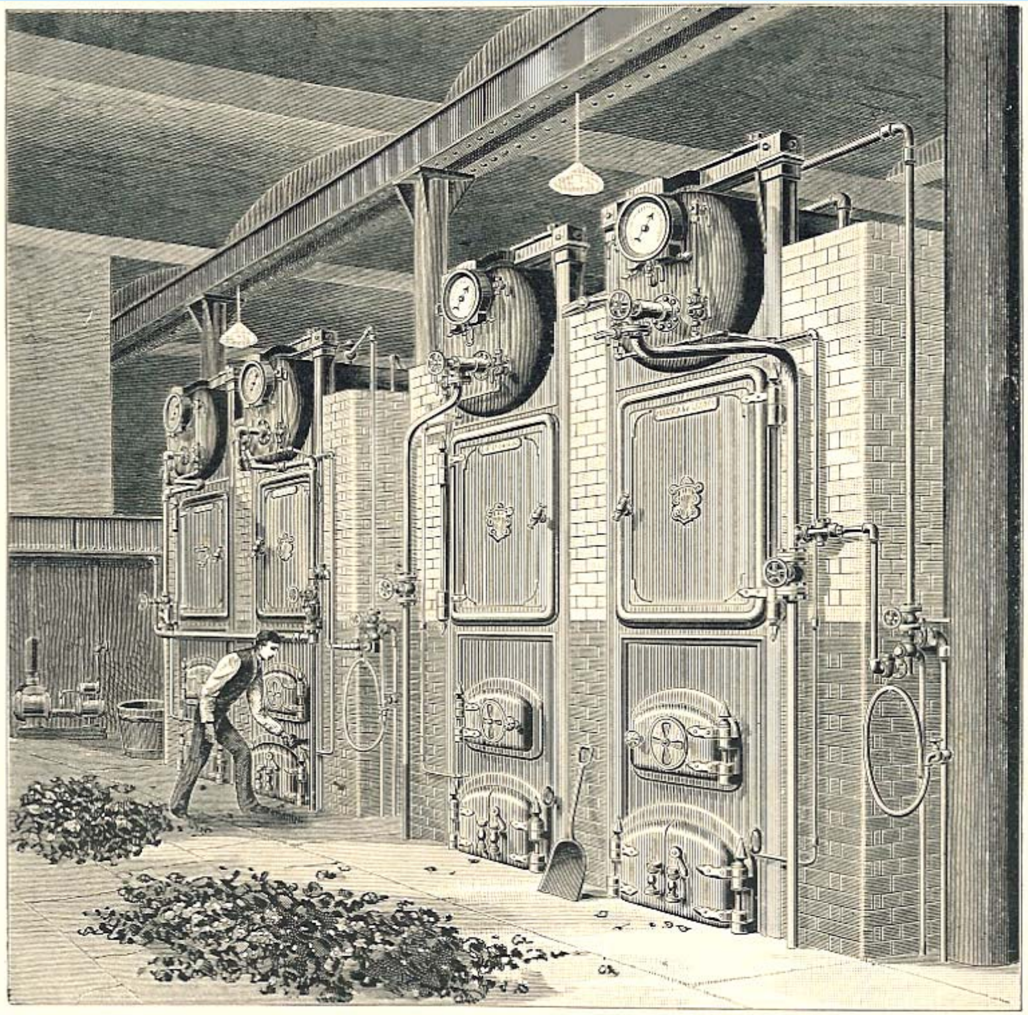




7.5’ x 45’ High Temperature Rotary Kiln

Steam Boilers Go Way Back...

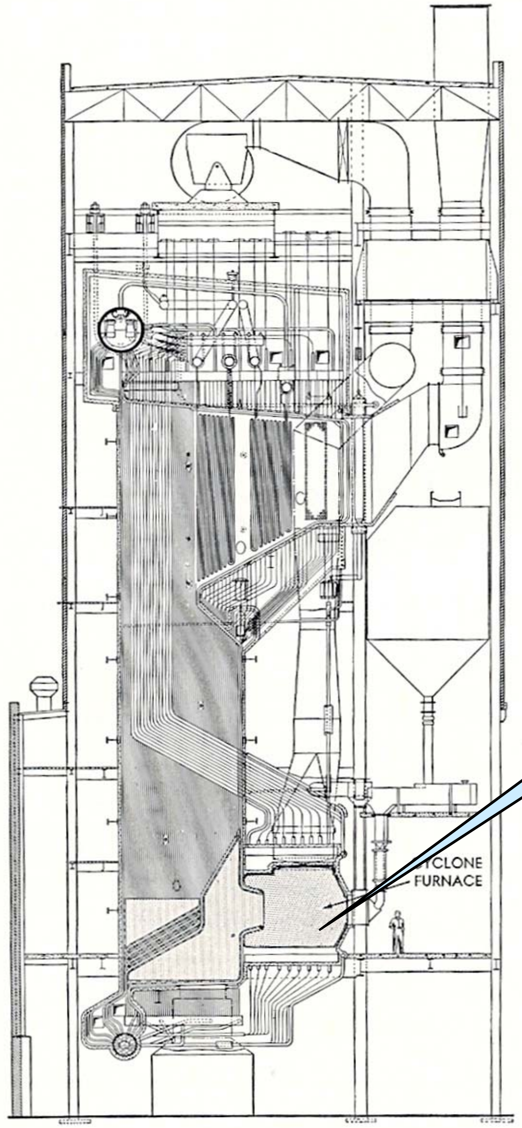
360 hp Coal Boiler in London for Power Production, 1888



Babcock & Wilcox Boilers at the Chelsea Electricity Supply Company's Station, Chelsea, Eng. 360 H. P. Erected 1888-9.
The Brush Electrical Engineering Co., Limited, London, Contractors.

Reference: Steam, Its Generation and Use, Babcock & Wilcox, NY, 1892,

Modern Radiant Boiler with Cyclone Furnace for Coal Firing



A Radiant boiler with Cyclone Furnaces adapted to burn hogged fuel with coal

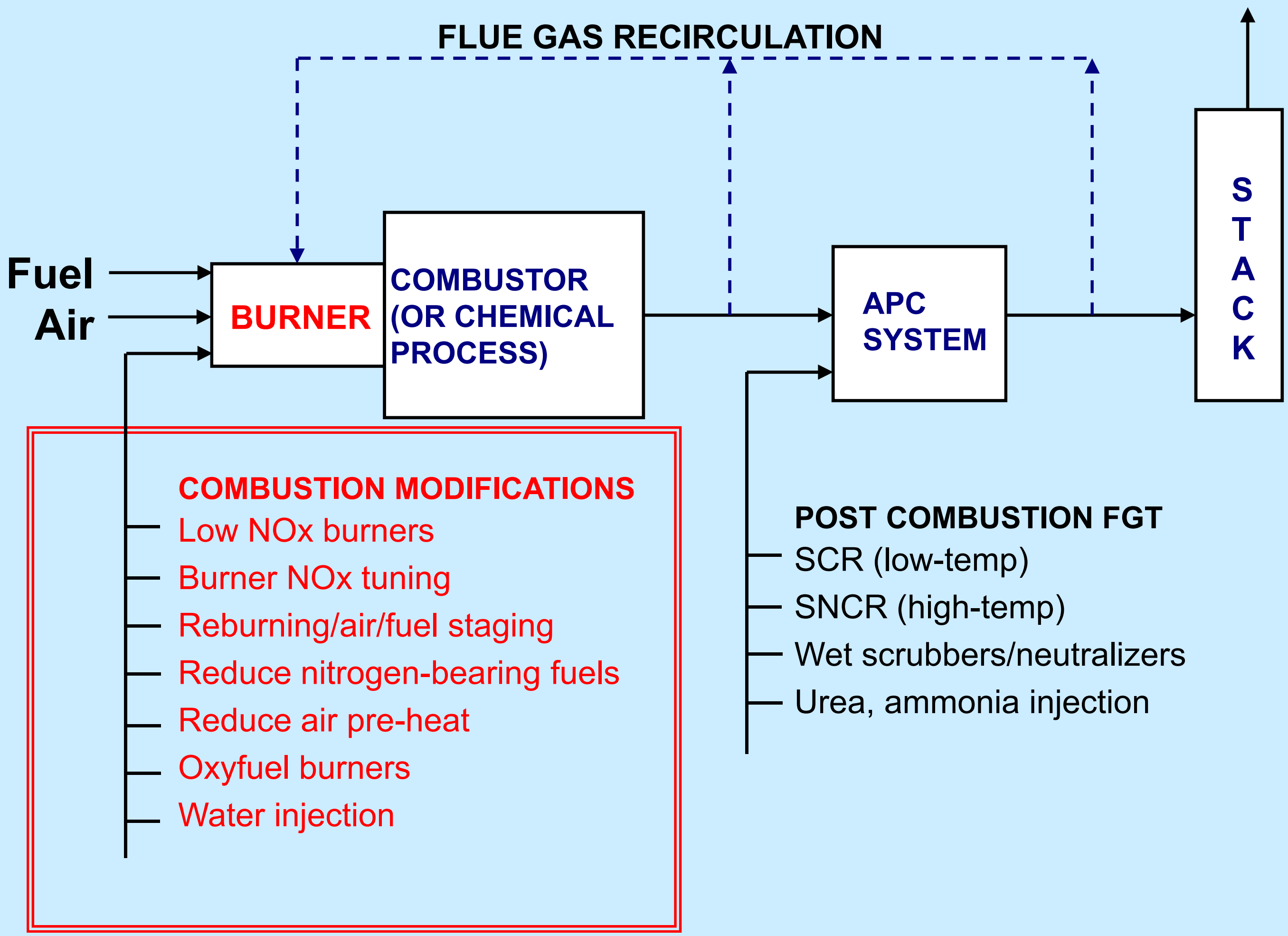
Cyclone Furnace

Reference: **Steam, Its Generation and Use, Babcock & Wilcox Company, NY 1963**

Scotch Marine Fire Tube Boiler for Gas & Oil

Used with Permission Cleaver Brooks

Air Pollution -- NOx Control Technologies



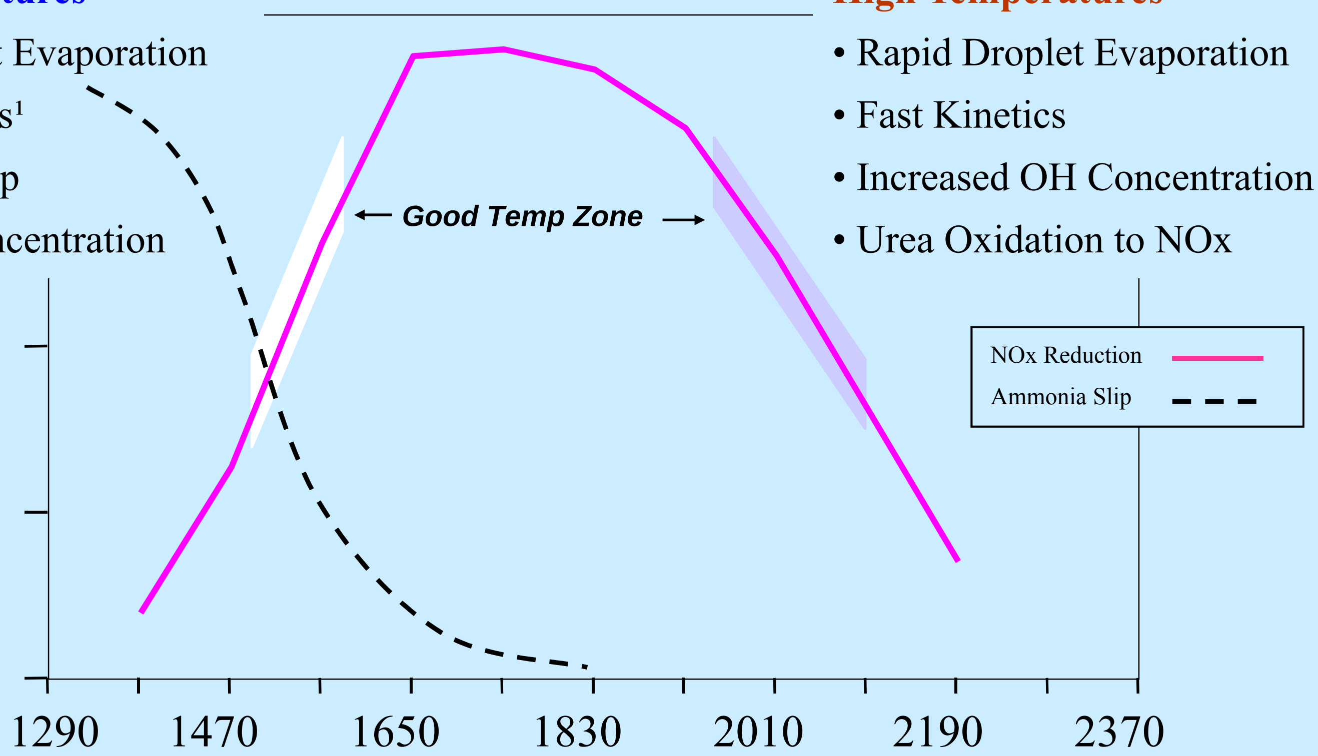
SNCR "RIGHT SIDE OF THE SLOPE" INJECTION

Low Temperatures

- Slow Droplet Evaporation
- Slow Kinetics[1]
- Ammonia Slip
- Low OH Concentration

High Temperatures

- Rapid Droplet Evaporation
- Fast Kinetics
- Increased OH Concentration
- Urea Oxidation to NOx



(1) Unable to generate hydroxyl radicals needed for urea decomposition – OH concentration increases with temperature.

FUEL TECH™
Technology for a renewed environment

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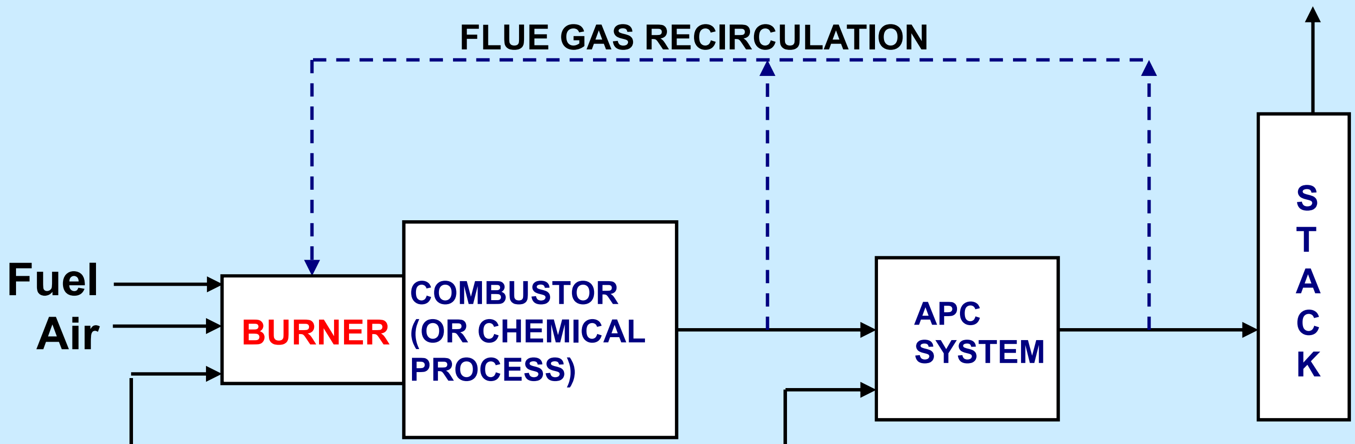
NOx Control Technologies
Post Combustion Flue Gas Treatment



COMBUSTION MODIFICATIONS
- Low NOx burners
- Reburning
- Oxyfuel burners
- Burner NOx tuning
- Eliminate nitrogen-bearing fuels
- Eliminate air pre-heat
- Water injection

POST COMBUSTION FGT
- SCR (low-temp)
- SNCR (high-temp)
- Wet scrubbers/neutralizers
- Urea, ammonia injection

Fouling Issues with SCR Catalysts

Sulfur levels an important parameter:

- Sulfur forms solid ammonium sulfate & ammonium bisulfate on catalyst
- Higher the SO2 and SO3, the higher the SCR temp must be
- Baghouse temps generally limited to 450 F
- Higher temps possible upstream of baghouse, but dust fouling and erosion an issue
- Can use dry reagent injection or spray dryer adsorber before baghouse to reduce sulfur levels at catalyst

End of Pipe APC Systems

Pollutants:

PM, Acid Gases, Mercury, Dioxins, CO, VOCs

Control Equipment:

Venturi Scrubber

Acid Gas Absorber

Spray Dryer Absorber

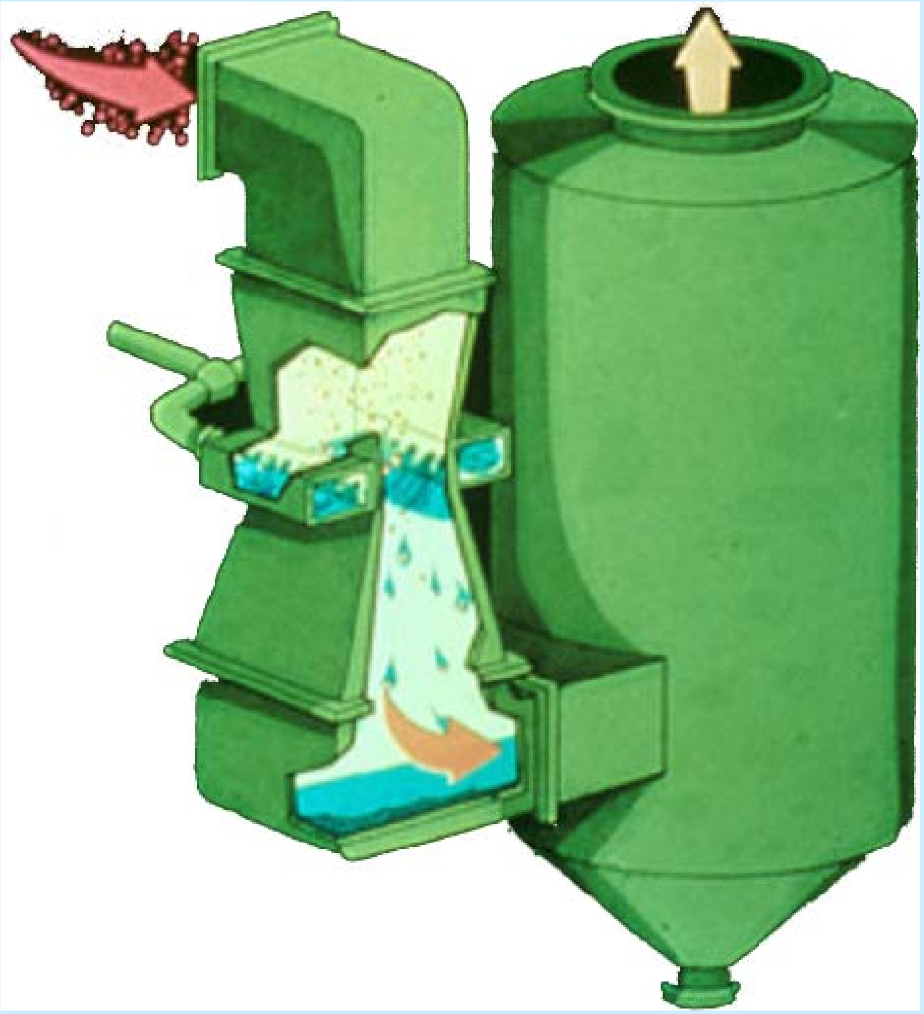
Baghouse

Dry ESP or wet ESP/IWES

Carbon and Lime Injection

Oxidizer

Venturi Scrubber



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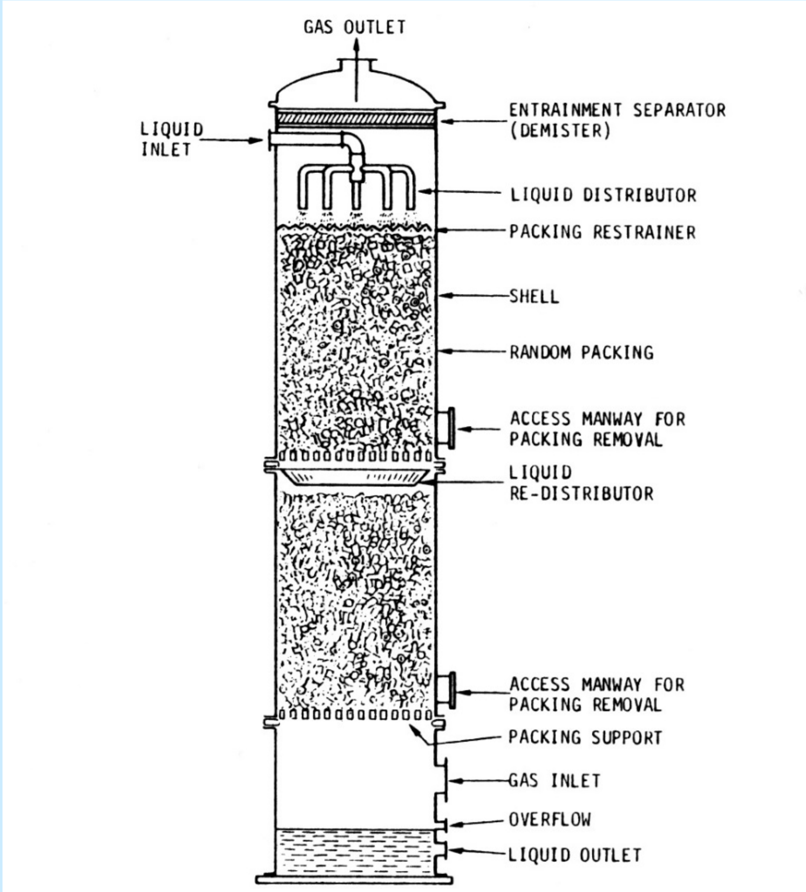
Countercurrent Packed Bed Column

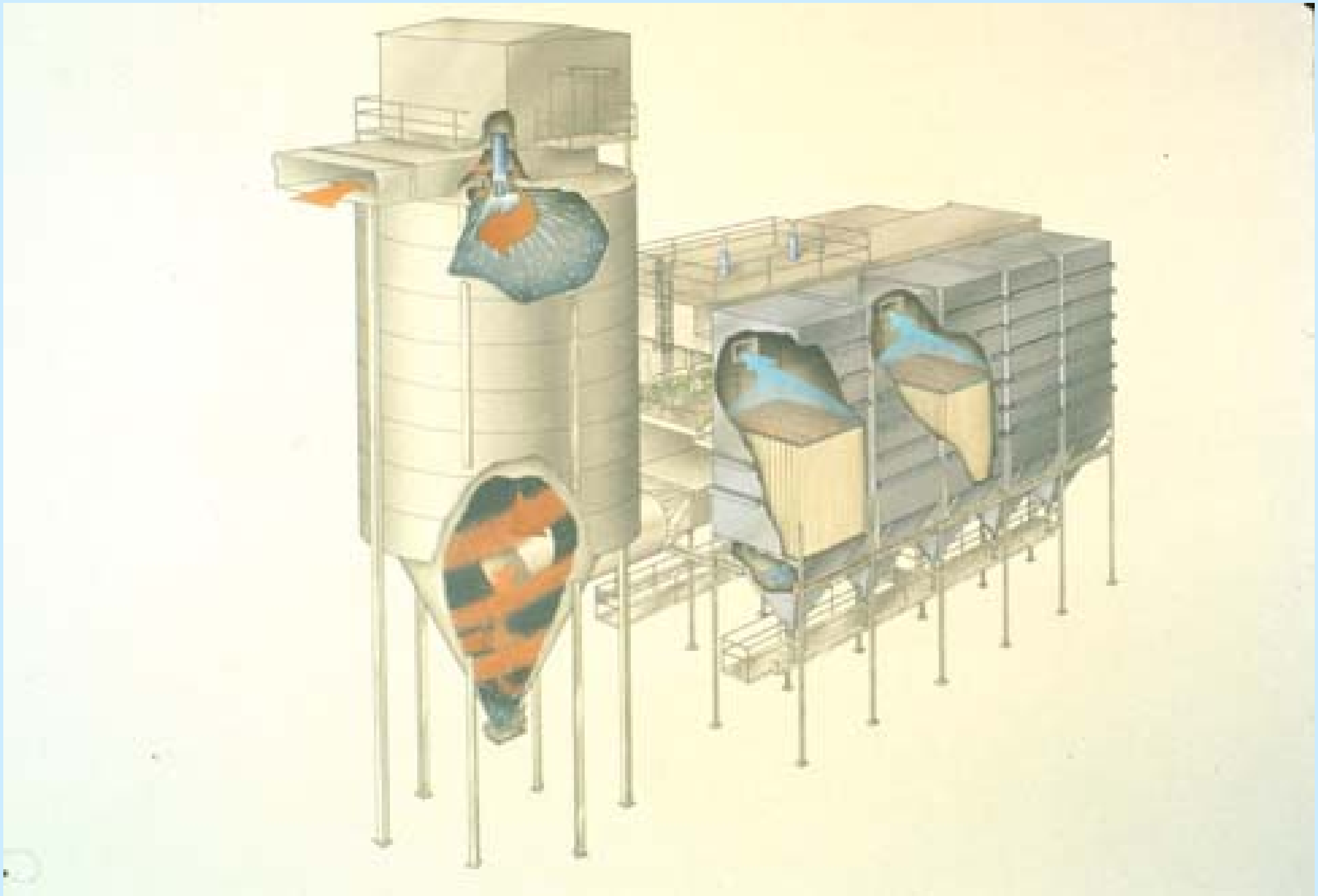


Countercurrent packed column.


Ceilcote
Air Pollution Control
Tellerette* Tower Packings
A significant advance in mass transfer technology.
Bulletin 12-20

Pulse Jet Baghouse, Bag, Cage, and Blowpipes

Spray Dryer Adsorber for Acid Gas Removal plus Baghouse



Metals In Combustion

- **Metals are neither created nor destroyed**
- **Oxides, chlorides, and sulfates of metals may be formed**
- **Fate varies with type of combustor and APC**
- **Low boiling point metals exit as vapors**
- **Some metals/salts form fine fume when condensed, e.g., P2O5**
- **Non-mercury/non-volatile metals easy to remove via baghouse or IWS**
- **Mercury requires carbon treatment in baghouse or condensing IWS**

Some References

North American Combustion Handbook - 2 Volumes

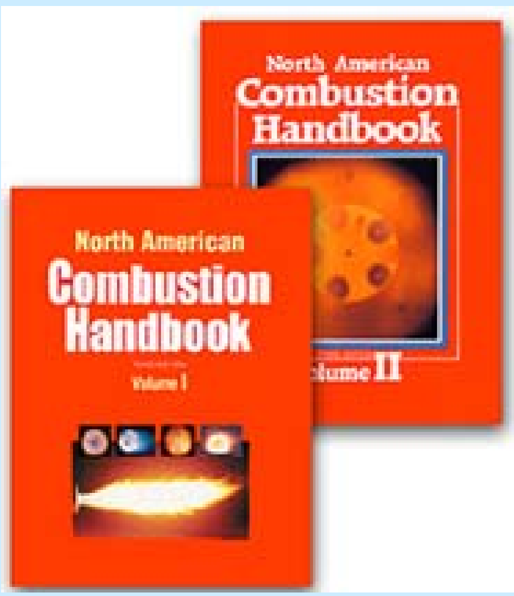
Order form: http://combustion.fivesgroup.com/literature/north-american/handbooks.html

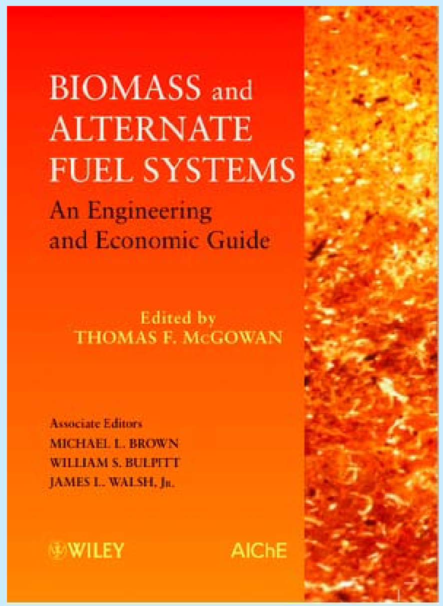
Biomass and Alternate Fuel Systems: An Engineering and Economic Guide

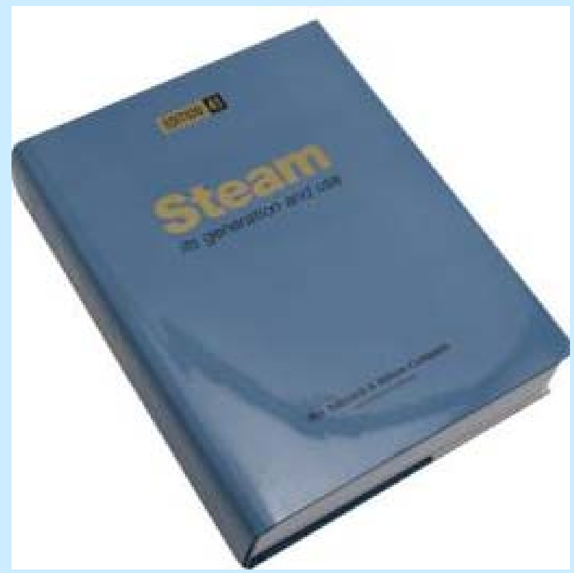
Order form: http://www.tmtsassociates.com/literature/book.html

B&W Steam Book

http://www.babcock.com/library/Pages/Steam-its-generation-and-use.aspx







New Boiler & Process Heater MACT

>10 and <30 MM Btu/hr

NESHAPS 40CFR63 Subpart JJJJJJ **Final 2/21/11**

EMISSION LIMITS FOR *AREA* SOURCE BOILERS (PTE < 10/25 tpy for HAPs)
[lb/MM Btu heat input except CO]

Source	Category	PM	Hg	CO ppmvd Daily Avg.
New	Coal Biomass Oil	0.42 0.07 0.03	4.8E–06 NA NA	400 (@ 3% oxygen) NA NA
Existing	Coal	NA	4.8E–06	400 (@ 3% oxygen)

Dropping below 15% biomass allows higher PM, CO

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New Boiler & Process Heater MACT (cont.)

>30 MM Btu/hr

NESHAPS 40CFR63 Subpart JJJJJJ **Final 2/21/11**

EMISSION LIMITS FOR *AREA* SOURCE BOILERS (PTE < 10/25 tpy for HAPs)
[lb/MM Btu heat input except CO]

Source	Category	PM	Hg	CO ppmvd Daily Avg.
New	Coal Biomass Oil	0.03 0.03 0.03	4.8E–06 NA NA	400 (@ 3% oxygen) NA NA
Existing	Coal	NA	4.8E–06	400 (@ 3% oxygen)

Assuming 10,000 dscf/MM Btu, equals ~ 0.02 gr/dscf or ~50 mg/m3

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Boiler MACT *Existing* Major Sources

Subcategory <u>*Existing Equipment*</u>	Particulate Matter PM lb/MM Btu (total selected metals)	Hydrogen Chloride (HCl) lb/MM Btu[a]	Mercury (Hg) lb/MM Btu	Carbon Monoxide (CO) (ppmvd @3% oxygen)[a]	Alternate CO CEMS limit, (pp @3% O2)[b]
Coal Stoker	0.040 (5.35E-05)	0.022	5.7E-06	160	340
Coal Fluidized Bed	0.040 (5.35E-05)	0.022	5.7E-06	140	230
Coal Fluidized Bed with FB Heat Exchang.	0.040 (5.35E-05)	0.022	5.7E-06	140	150
Pulverized Coal	0.040 (5.35E-05)	0.022	5.7E-06	130	320
Biomass Wet Stoker/Sloped Grate/Other	0.037 (2.4E-04)	0.022	5.7E-06	1500	720
Biomass Kiln-Dried Stoker/Sloped Grate/Other	0.032 (4.0E-03)	0.022	5.7E-06	460	ND

For 13000 Btu/lb coal, 100% Hg emitted, limit =0.000007% Hg in coal

TMTS

Boiler MACT *Existing* Major Sources

Subcategory <u>*Existing Equipment*</u>	Particulate Matter PM lb/MM Btu (total selected metals)	Hydrogen Chloride (HCl) lb/MM Btu[a]	Mercury (Hg) lb/MM Btu	Carbon Monoxide (CO) (ppmvd @3% oxygen)[a]	Alternate CO CEMS limit, (pp @3% O2)[b]
Biomass Fluidized Bed	0.011 (1.2E-03)	0.022	5.7E-06	470	310
Biomass Suspension Burner	0.051 (6.5E-03)	0.022	5.7E-06	2400	2000[c]
Biomass Dutch Ovens/Pile Burners	0.028 (2.0E-03)	0.022	5.7E-06	770	520[c]
Biomass Fuel Cells	0.020 (5.8E-03)	0.022	5.7E-06	1100	ND
Biomass Hybrid Suspension Grate	0.44 (4.5E-04)	.022	5.7E-06	2800	900

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Boiler MACT Existing Major Sources

Subcategory *Existing Equipment*	Particulate Matter PM lb/MM Btu (total selected metals)	Hydrogen Chloride (HCl) lb/MM Btu[a]	Mercury (Hg) lb/MM Btu	Carbon Monoxide (CO) (ppmvd @3% oxygen)	Alternate CO CEMS limit, (pp @3% O2)[b]
Heavy Liquid	0.062 (2.0E-04)	0.0011	2.0E-06	130	ND
Light Liquid	0.0079 (6.2E-05)	0.0011	2.0E-06	130	ND
Non- continental liquid	0.27 (8.6E-04)	0.0011	2.0E-06	130	ND
Gas 2 (other process gases)	0.0067 (2.1E-04)	0.0017	7.9E-06	130	ND

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Boiler MACT Existing Major Sources

Subcategory *Existing Equipment*	Particulate Matter PM lb/MM Btu (total selected metals)	Hydrogen Chloride (HCl) lb/MM Btu[a]	Mercury (Hg) lb/MM Btu	Carbon Monoxide (CO) (ppmvd @3% oxygen)	Alternate CO CEMS limit, (pp @3% O2)[b]
Gas 2 (other process gases)	0.0067 (2.1E-04)	0.0017	7.9E-06	130	ND
Light Liquid	0.0079 (6.2E-05)	0.0011	2.0E-06	130	ND
Non- continental liquid	0.27 (8.6E-04)	0.0011	2.0E-06	130	ND

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0.0011 lb/MM Btu = ~ 0.007 gr/dscf or ~20 mg/m3

Boiler MACT New Major Sources

Subcategory *New Equipment*	Particulate Matter PM lb/MM Btu (total selected metals)	Hydrogen Chloride (HCl) lb/MM Btu[a]	Mercury (Hg) lb/MM Btu	Carbon Monoxide (CO) (ppmvd @3% oxygen)	Alternate CO CEMS limit, (ppm @3% O2)[b]
Coal Stoker(*), Fluid Bed(**), Fluidized Bed with Preheat Pulverized (***), Pulverized(****)	0.0011 (2.3E-05)	0.0022	8.0E-07	130* 130** 140*** 130****	340* 230** 150*** 320****
Biomass Wet Stoker/Sloped Grate/Other	0.030 (2.6E-05	0.0022	8.0E-07	620	390
Biomass Fluid Bed	0.0098 (8.3E-05)	0.0022	8.0E-07	230	310
Biomass Suspension Burner	0.030 (6.5E-03)	0.0022	8.0E-07	2400	2000[c]
Biomass Dutch Ovens/Pile Burners	0.0032 (3.9E-05)	0.0022	8.0E-07	330	520[c]

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Boiler MACT New Major Sources

Subcategory ***New Equipment***	**Particulate Matter PM lb/MM Btu (total selected metals)**	**Hydrogen Chloride (HCl) lb/MM Btu**[a]	**Mercury (Hg) lb/MM Btu**	**Carbon Monoxide (CO) (ppmvd @3% oxygen)**	**Alternate CO CEMS limit, (ppm @3% O2)**[b]
Biomass Fuel Cells	0.020 (2.9E-05)	0.0022	8.0E-07	910	ND
Biomass Hybrid Suspension Grate	0.026 (4.4E-04)	0.0022	8.0E-07	1100	900
Heavy Liquid	0.013 (7.5E-05)	4.4E-04	4.8E-07	130	ND
Light Liquid	0.023 (8.6E-04)	4.4E-04	4.8E-07	130	ND
Gas 2 (other process gases)	0.0067 (2.1E-04)	0.0017	8.0E-07	130	ND

[a] 3-run average, unless otherwise available
[b] 30-day rolling average, unless otherwise noted
[c] 10-day rolling average

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WL Gore Remedia™ Filters for Multipollutant Removal:

- **Fabric filters for PM**
- **Dioxin removal**
- **Carbon injection for Hg**
- **Dry reagent for HCl and SO2**

Tri-Mer High-Temp Ceramic Filters for Multipollutant Removal:

- **High temp ceramic filters for PM**
- **Catalyst for SCR NOx control (1” thick bags), with temps as low as 400F**
- **Dry reagent injection for HCl &SO2**
- **Carbon injection for Hg**
- **Catalytic VOC destruction**

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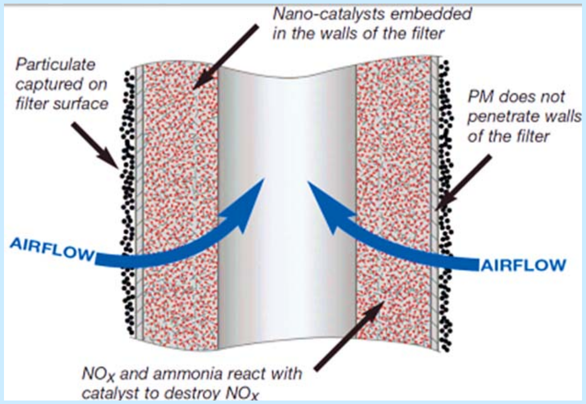
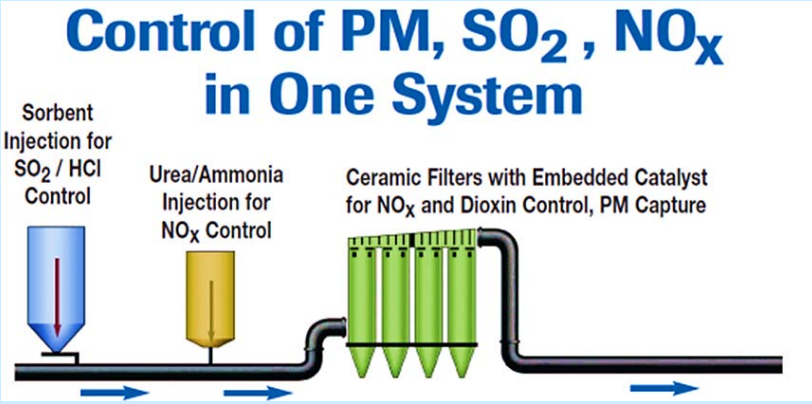
Ceramic Filters for Multipollutant Removal

High temp PM removal

Courtesy of Tri-Mer

PM and NOx with reagent





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Filters for Multipollutant Removal – Tri-Mer Installation

Courtesy of Tri-Mer

PAC for Mercury Removal

Typical Hg level = 0.1 ppm in coal; apprx. 60% emitted

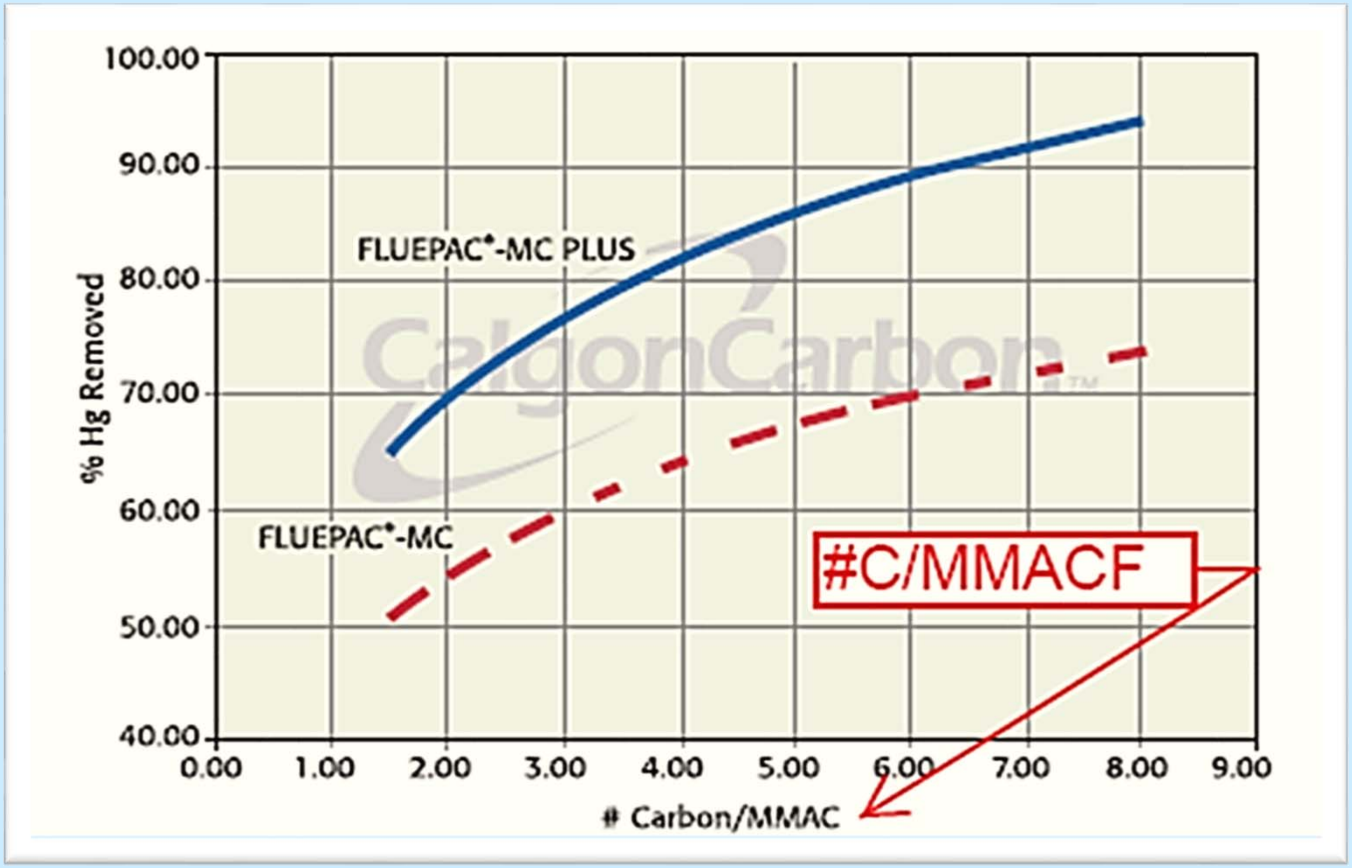
Hg removal methods:

- **PAC before baghouse or precipitator (~40-60% removal at 0.08 g/m^3 loading)**
- **Use increased levels of unburned carbon to act as adsorbent (this carbon loss reduces fuel efficiency)**
- **Typical carbon injection rate - coal boiler: 7-10 lb/MM acf for ESPs, and 2-5 lb/MM acf for FF**
- **Depends on type of coal, $\leq$350F temp required!**
- **Some use high ratio baghouse downstream of other APC just for carbon injection**

- **Or — removal with wet scrubbers (e.g., B&W additive reagent to SO_2 scrubber liquid)**

AWMA Journal, 11/03, pgs 1318-1325; *AWMA Journal*, 8/02, pgs 902-911; *Power Engineering*, 10/04, page 41

Mercury Removal With PAC



Used with permission, Calgon Carbons, from
FLUEPAC®-MC PLUS Powdered Activated Carbon

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Heat Exchangers to Cut Fuel Use and Emissions

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Heat Exchanger Calculations

HX Effectiveness = E = $\dfrac{C_h\,(T_{h\ in} - T_{h\ out})}{C_{min}\,(T_{h\ in} - T_{c\ in})}$

Where:

C min is the smaller of $m_h\, c_{ph}$ **or** $m_c\, c_{pc}$**, the hourly heat capacity and**

m is the mass in lb/hr c_p **is heat capacity in Btu/hr-°F**

h is hot stream

c is cold stream

Rate of heat exchange is q, and $q = E\, C_{min} \times (T_{h\ in} - T_{c\ in})$

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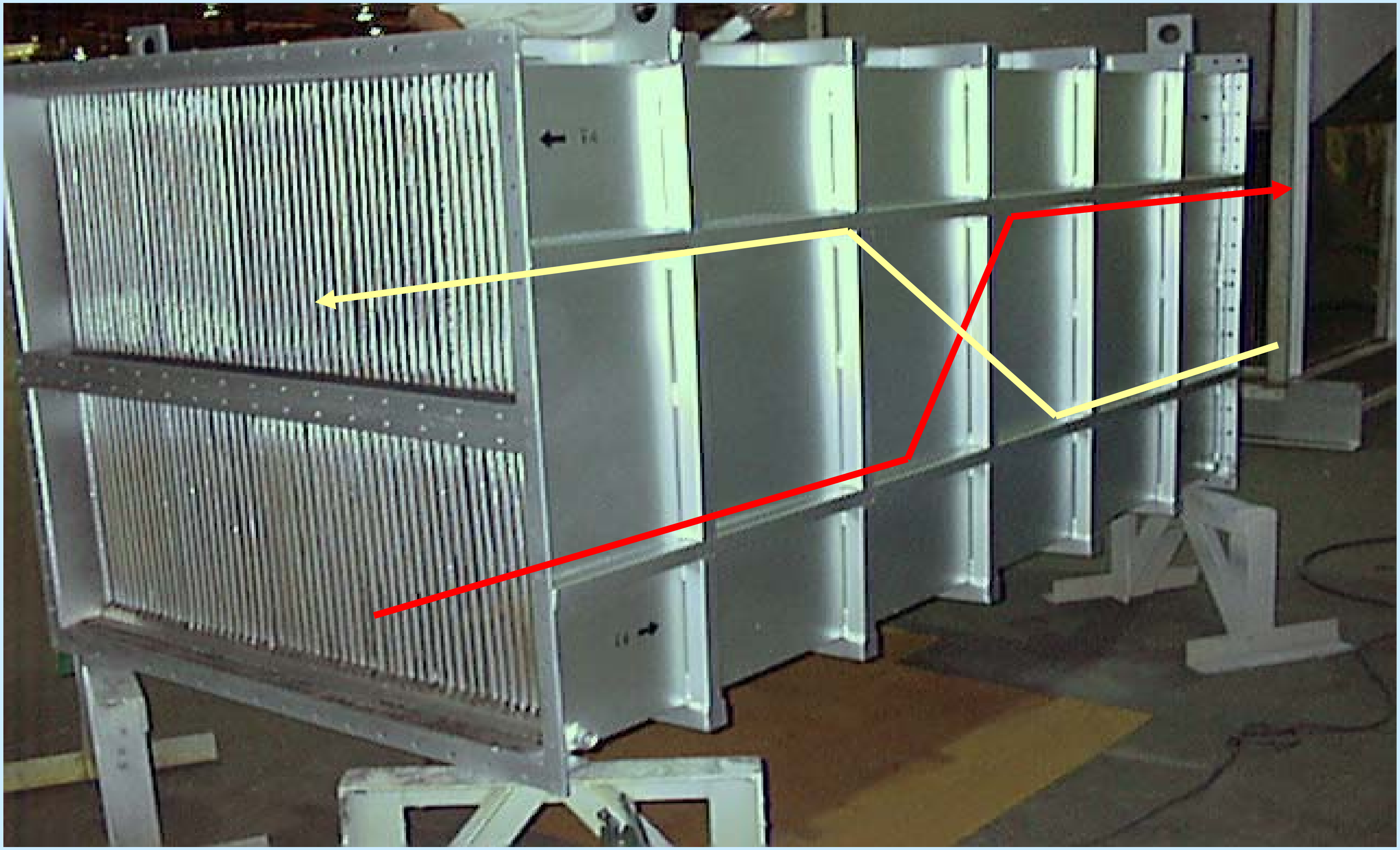
Air to Air Heat Exchanger Basics

- Alloys used to withstand corrosion and high temps
- For air-to-air exchangers, failures are more frequent with inlet gas temp >1400°F
- Failures more frequent with dust & chlorides
- Higher temperatures are possible with switched bed ceramic heat exchangers, used in the steel industry and for RTOs.
- Efficiency suffers due to lower gas temperature and lack of radiant heat transfer. Example: Waste heat boiler typical max 65% efficient, vs. the usual 80% plus for fuel fired boilers.
- Economics usually poor at < 5 MM Btu/hr

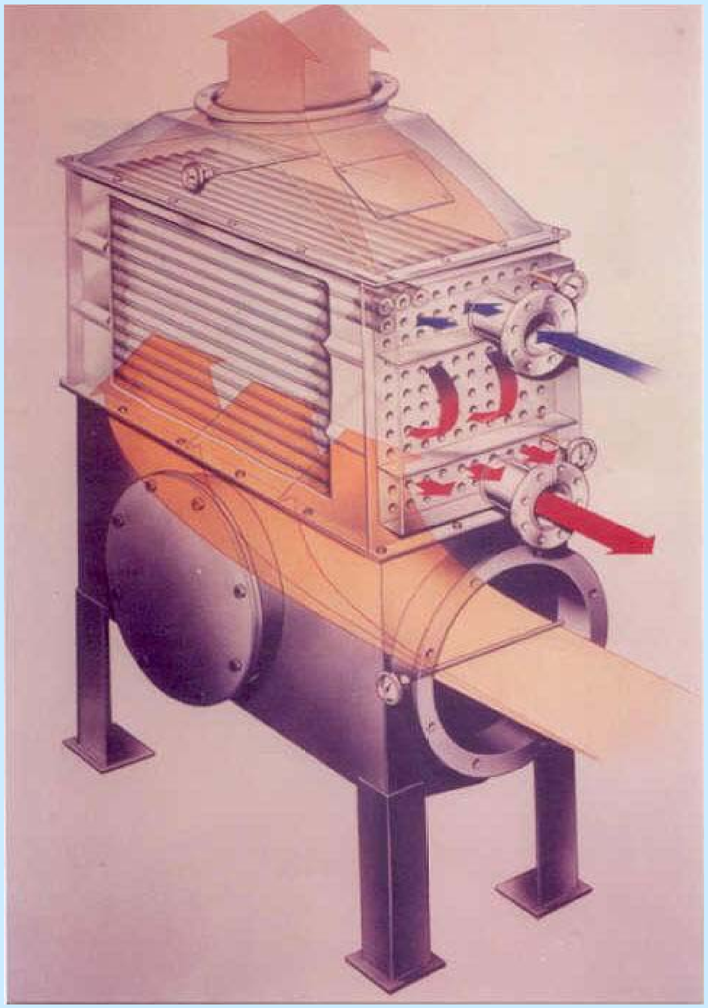
Example Air to Air HX Thermo-Z Temp-X-Changer
Arrows Show Flow Pattern



Ref: Used with permission, DesChamps Technologies

Air to Water HX -- Economizer

Gas and Water Flows in an Economizer



Two Scotch Marine Boilers with Economizer in the Middle

Used with permission, Sidel Systems, www.sidelsystems.com

Air to Steam - Fire Tube Waste Heat Boiler with External Steam Drum

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Questions?

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