Combustion Technology for Energy Conservation in Industry

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Schedule

Chapter 1

- Combustion & Flame
- Fuel Type
- Classification of Burner
- New Combustion Technology
- Combustion Technology for Energy Saving and Low Environmental Pollution

Chapter 2

- Decomposition of Burners
- Industrial Furnace Conservation Techniques
  - Furnace Pressure
  - Furnace Design
- Explanation of the Furnace in ECCJ Model Factory
- How to Save Energy

Definition of Combustion and Flame

- Combustion is defined as the process which changes the chemical energy of fuel to the thermal energy by oxidizing reaction with oxidant like air, which **rapid heat and visible ray release** is accompanied.
- Flame is the state of gas phase and formed generally in the flow region of mixture of fuel, air and burning products.

Fuel Type (1) --- Gas Fuel

- High Combustion Efficiency
- Firing Low Excess Air Ratio
- Easy Combustion Control
- Usually No Sulfur Content (No SOx Emission)
- Typical Gas Fuel

  LNG, LPG, COG, Hydrogen, etc

Name	Component %									Density	Low Calorific Value	Theoretical Air Requirement	Theoretical Combustion Product m^3_N/m^3_N		
	CO_2	CO	CH_4	C_3H_8	C_4H_{10}	CmHn	H_2	O_2	N_2	kg/m^3_N	MJ/m^3_N	m^3_N/m^3_N	CO_2	H_2O	N_2
Butane Gas	0	0	0	0	100	0	0	0	0	2.593	118.6	31.09	4.00	5.00	24.59
Propane Gas	0	0	0	100	0	0	0	0	0	1.967	91.3	23.91	3.00	4.00	18.91
Natural Gas	0	0	89.8	2.9	1.4	C_2H_6 5.9	0	0	0	0.815	40.2	10.66	1.15	2.16	8.42
City Gas (13A)	0	0	88.0	4.0	2.0	C_2H_6 6.0	0	0	0	0.841	41.7	11.00	1.20	2.20	8.65
City Gas (6A)	0	0	0	1.0	21.1	0	0	16.4	61.5	1.570	27.1	5.80	0.84	1.06	5.18
COG	3.0	7.0	27.0	0	4.0	0	57.0	0.5	1.5	0.467	19.1	4.74	0.45	1.19	3.72
BFG	21.1	22.0	0	0	0	0	2.8	0	54.1	1.367	3.0	0.59	0.43	0.03	1.01

Table 1. Properties of Gas Fuel

Fuel Type (2) --- Liquid Fuel

- Relatively Cheaper than Gas Fuel
- Easy to Handle and Transport
- Uniform Calorific Value (42 MJ/kg)
- Necessity of Sulfur and Ash Treatment
- Necessity of Heating up (Fuel Oil Type2&3)
- Typical Liquid Fuel

  Kerosene, Light Oil, Fuel Oil Type1 etc.

Name	Component wt %							Density	kinematic Viscosity	Low Calorific Value	Theoretical Air Requirement	Theoretical Combustion Product m^3N/kg			
	C	H	O	N	S	H_2O	Ash	g/cm^3	mm^2/s	MJ/kg	m^3N/kg	CO_2	H_2O	SO_2	N_2
Kerosene	85.7	14.0	0	0	0.5	0	0	0.78～0.83	2	43.5	11.40	1.59	1.56	0.00	9.02
Light Oil (Diesel Oil)	85.9	13.6	0	0	0.5	0	0	0.81～0.84	4	43.0	11.20	1.60	1.51	0.00	8.87
Fuel Oil Type 1	85.9	12.0	0.7	0.5	0.5	0.3	0.05	0.85～0.88	～50	42.7	10.90	1.60	1.34	0.00	8.61
Fuel Oil Type 2	84.5	11.3	0.4	0.4	3.0	0.4	0.05	0.90～0.93	～150	41.3	10.70	1.58	1.27	0.02	8.44
Fuel Oil Type 3	84.0	10.9	0.5	0.4	3.5	0.5	0.10	0.93～0.95	< 1000	41.4	10.50	1.57	1.21	0.02	8.27
Gasoline	85.0	15.0	0	0	0	0	0	0.70～0.74	> 1	44.1	11.60	1.59	1.68	0.00	9.18

Table 2. Properties of Liquid Fuel

Fuel Type (3) --- Solid Fuel

- Difficult to Handle and Transport
- Relatively Cheaper than Gas and Liquid Fuel
- Necessity of Sulfur and Ash Treatment
- Necessity of Pretreatment

  (Crushing, Gasification, Liquefaction, etc)
- Typical Solid Fuel

  Coal (Many Types), Cokes, etc

Name	Component wt %							True Specific Gravity	Low Calorific Value	Theoretical Air Requirement	Theoretical Combustion Product m^3N/kg			
	C	H	O	N	S	H_2O	Ash	g/cm^3	MJ/kg	m^3N/kg	CO_2	H_2O	SO_2	N_2
Foundry Coke	85.5	0.3	0.1	0	0.5	0.3	12.6	1.8～2.0	28.9	7.75	1.61	0.03	0.00	6.09
Iron-making Coke	79.4	0.4	0	0	0.6	0.8	18.4	1.8～1.9	27.0	7.21	1.49	0.05	0.00	5.66
Gas Coke	75.7	0.4	0.8	0	1.1	3.9	19.8	～1.8	26.1	6.73	1.39	0.09	0.01	5.29
Peat	21.0	6.3	62.9	1.1	0.6	0	6.0		5.5	1.51	0.40	0.72	0.00	1.20
Brown Coal	42.4	6.6	42.1	0.6	1.1	0	7.2		16.1	4.16	0.79	0.74	0.01	3.28
Bituminous Coal	78.0	5.2	7.5	1.3	1.0	0	7.1	1.25～1.45	32.1	8.11	1.46	0.59	0.01	6.38
Anthracite	84.4	1.9	4.4	0.6	0.9	0	7.8	1.3～1.8	30.3	7.89	1.58	0.22	0.01	6.20

Table 3. Properties of Solid Fuel

Classification of Burner

- ☞ Type of Draft

  Natural Draft & Forced Draft
- ☞ Heating Method

  Direct & Indirect Heating
- ☞ Air / Fuel Mixing Method

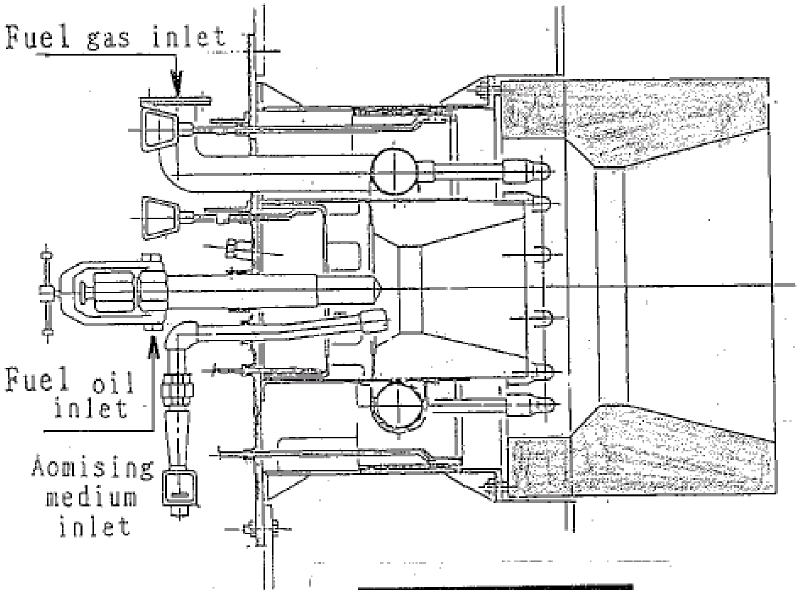
  Premix & Diffusion Mixing
- ☞ Oil Atomising Method

  With & Without Atomising Medium

Classification of Industrial Burners

1. Type of Draft
   - Natural Draft
   - Forced Draft
2. Heating Method
   - Indirect Heating (Radiant Tube)
   - Direct Heating
3. Air/Fuel Mixing Method
   - Premix
     - Induced
     - Forced
   - Diffusion
     - Nozzle Mix
     - Combustor
4. Oil Atomizing Method
   - with Atomizing Medium
     - High Pressure
     - Low Pressure
   - without Atomizing Medium
     - Pressure Jet
     - Rotary Cup
5. Air/Fuel Ratio Control Method
   - Use of Proportioning Burner
   - Use of Pressure Equalizing Regulator
   - Flow Control

Classification by Type of Draft



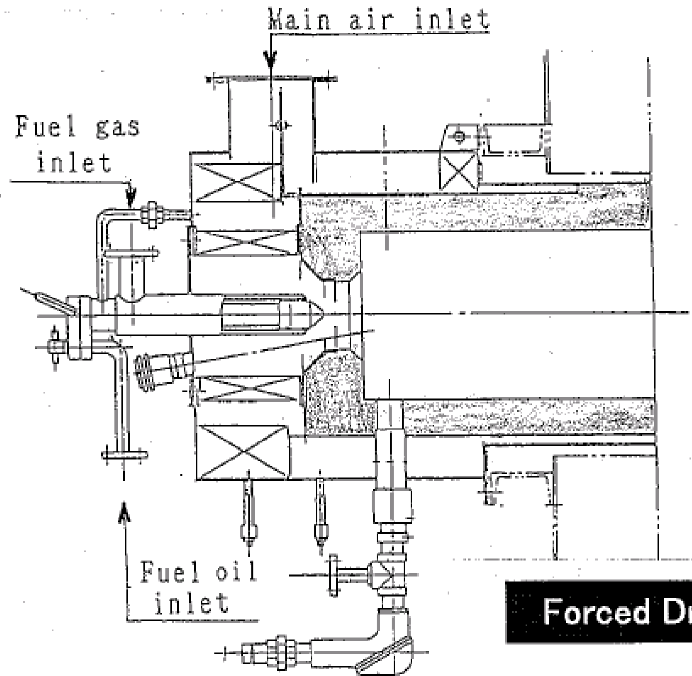
Natural Draft

Oil/gas combination burner (Model:PCMG)

Air/fuel ratio : 1.3～1.5

Prehdated air : not used

Turndown : 1:4



Forced Draft

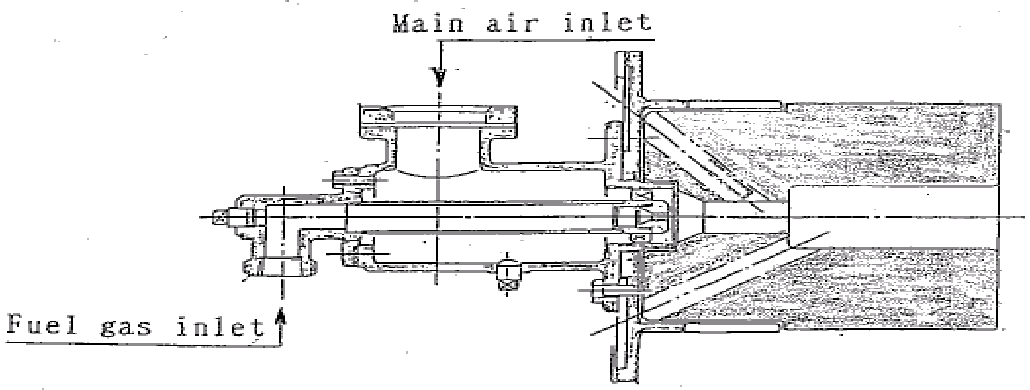
Vortometric oil/gas combination burner (Model:CVS)

Air/fuel ratio : 1.05～1.1

Preheated air : to be used

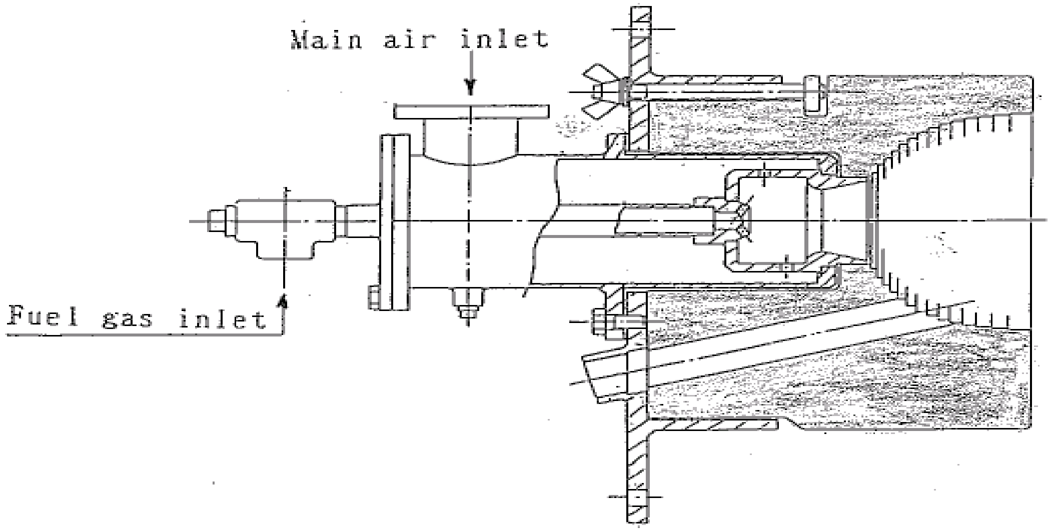
Turndown : 1:10

Classification by Heating Method　Direct



Convection heating

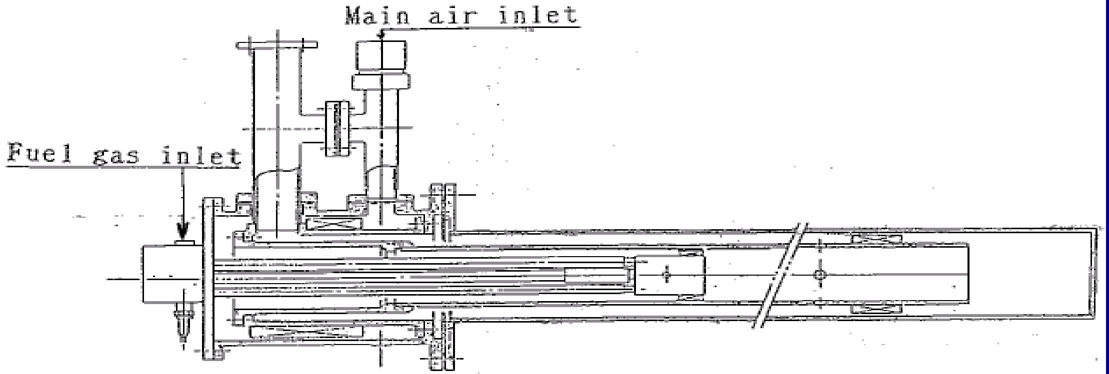
High momentum gas burner (Model:HMG)



Radiative heating

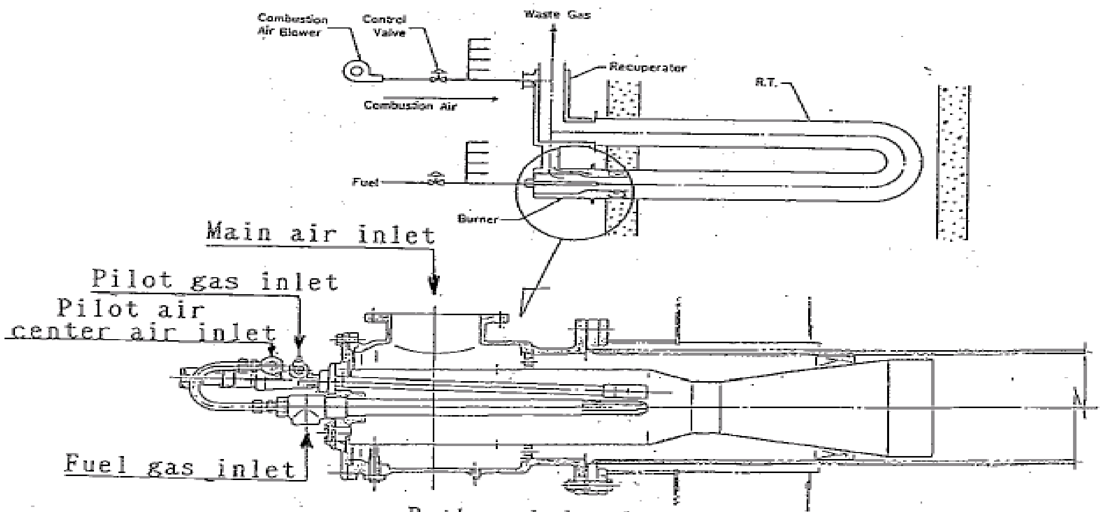
Flat flame gas buener (Model:HFB)

Classification by Heating Method　Indirect



Single ended tube

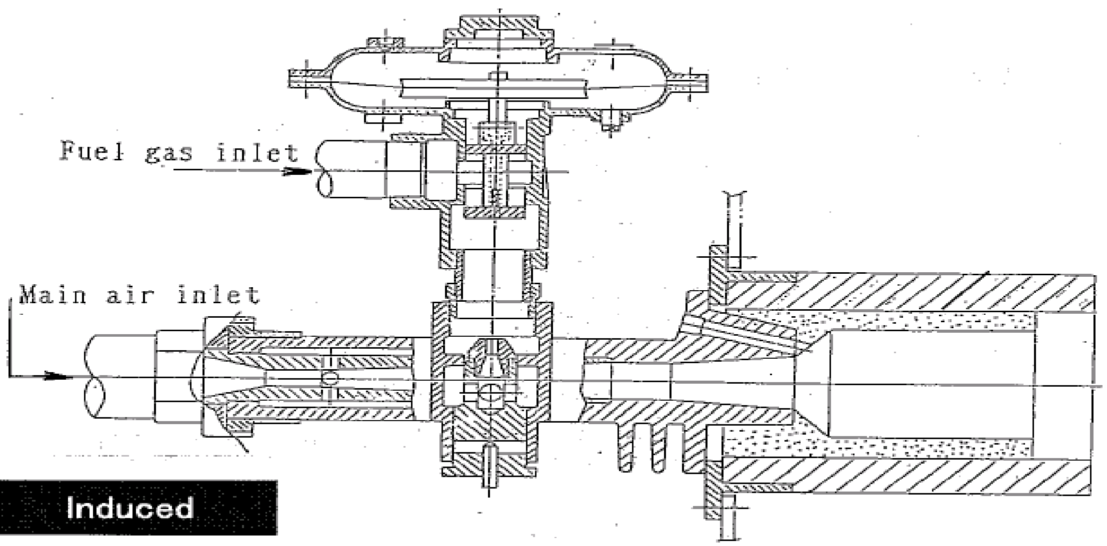
Concentric radiant tube unit (Model:CRB)



Both ended tube

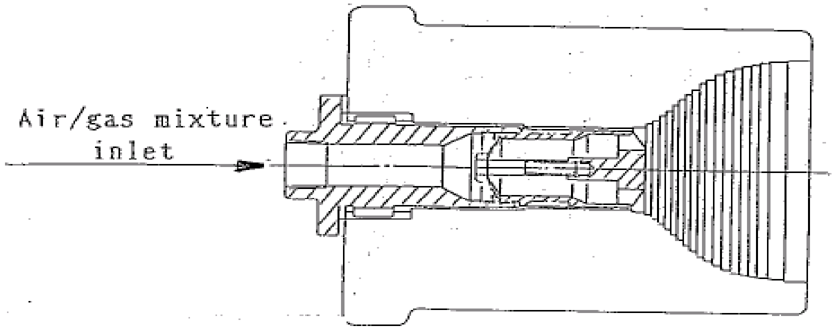
Low NOx rediant tube burner (Model:RBG-NR)

Classification by Air/Fuel Mixing Method Premix



Induced

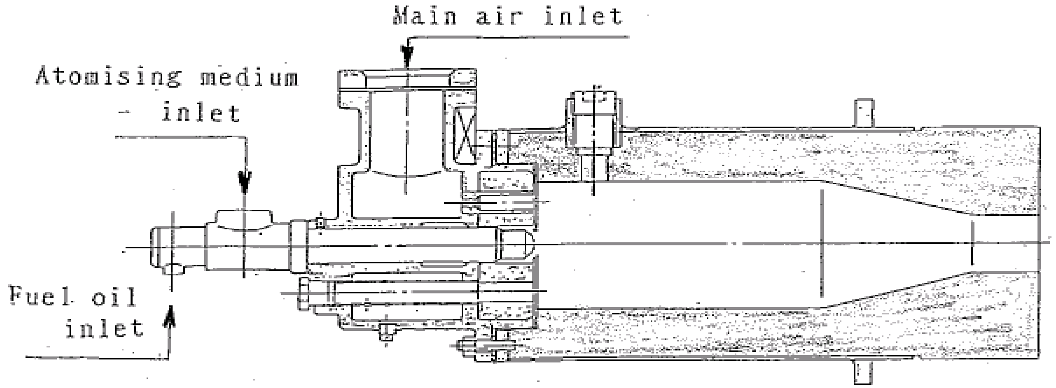
Low pressure velocity burner (Model:LP)



Forced

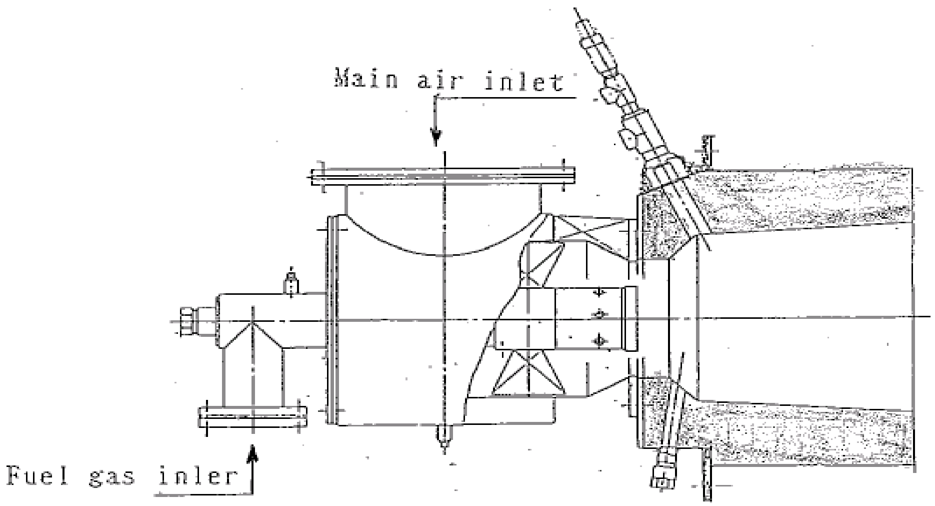
Radiation gas burner (Model:EFB)

Classification by Air/Fuel Mixing Method　Diffusion



Combustor

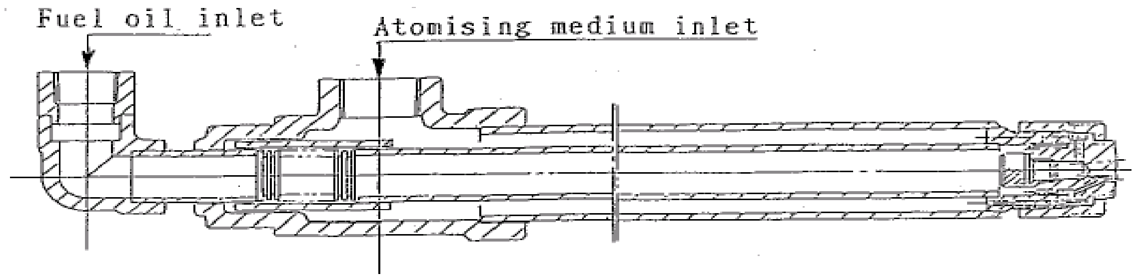
High speed excess air buener (Model:HC)



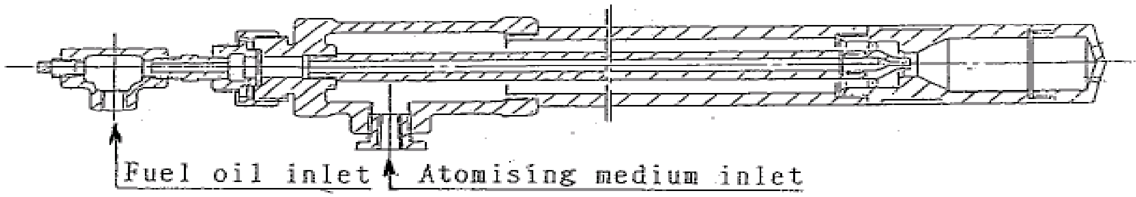
Nozzle Mix

Nozzle mix gas burner (Model:NG)

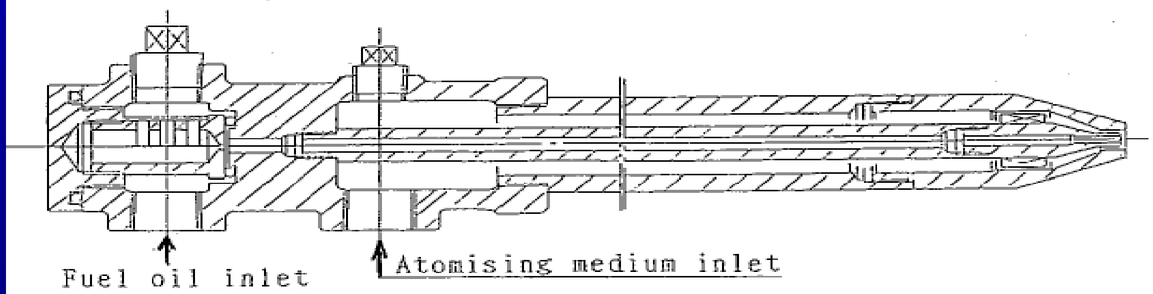
Classification by atomizing Method   Compressed Medium



Y-jet atomiser (Model:SEA)

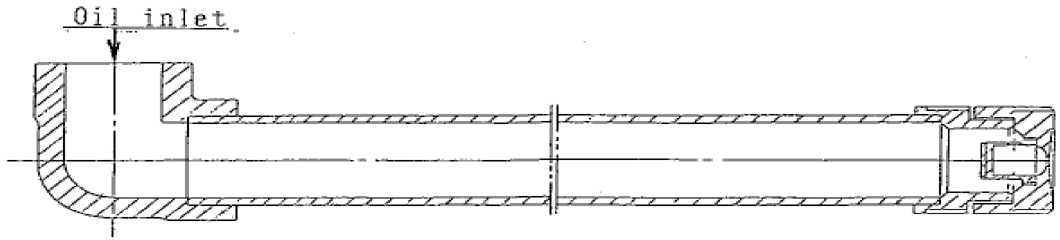


Internal mix atomiser (Model:MB)

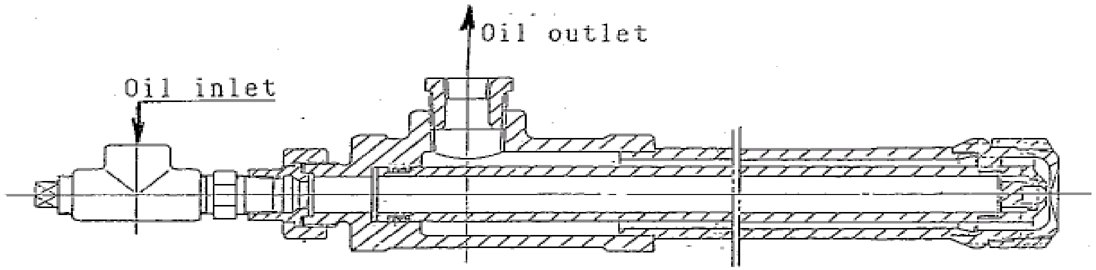


External mix atomiser (Model:HB)

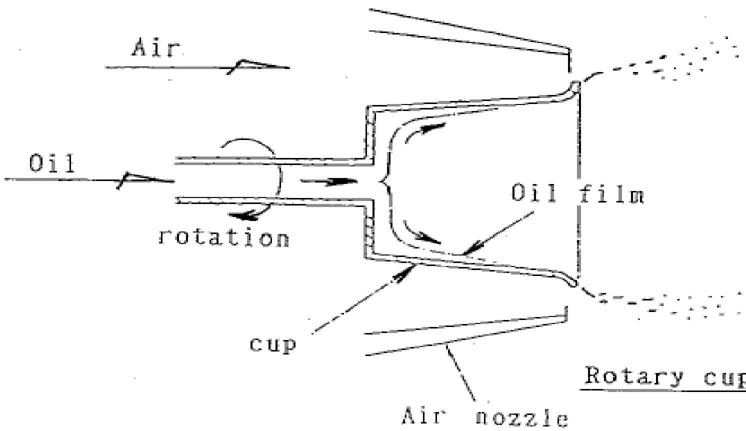
Classification by atomizing Method No Atomizing Medium



Pressure jet atomiser-No oil return

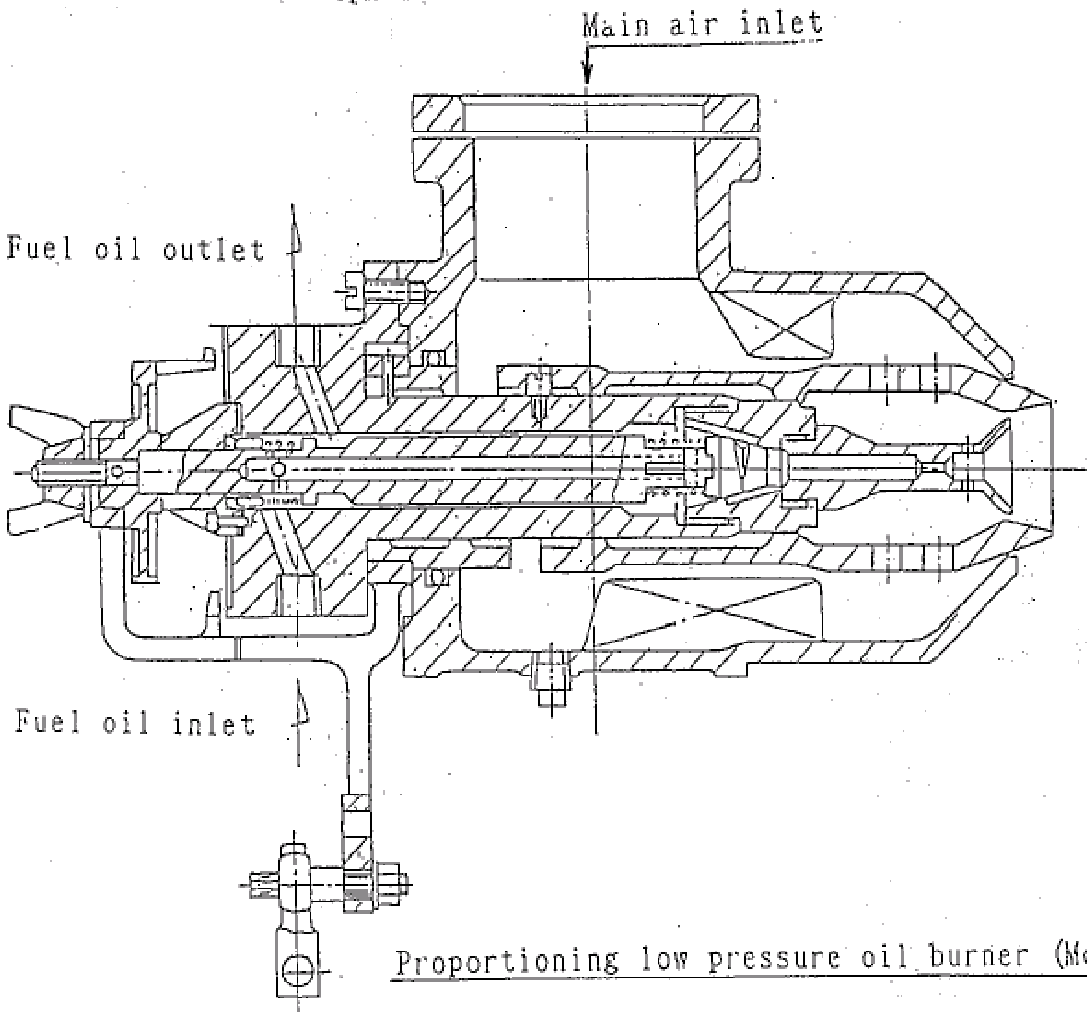


Pressure jet atomiser-oil return

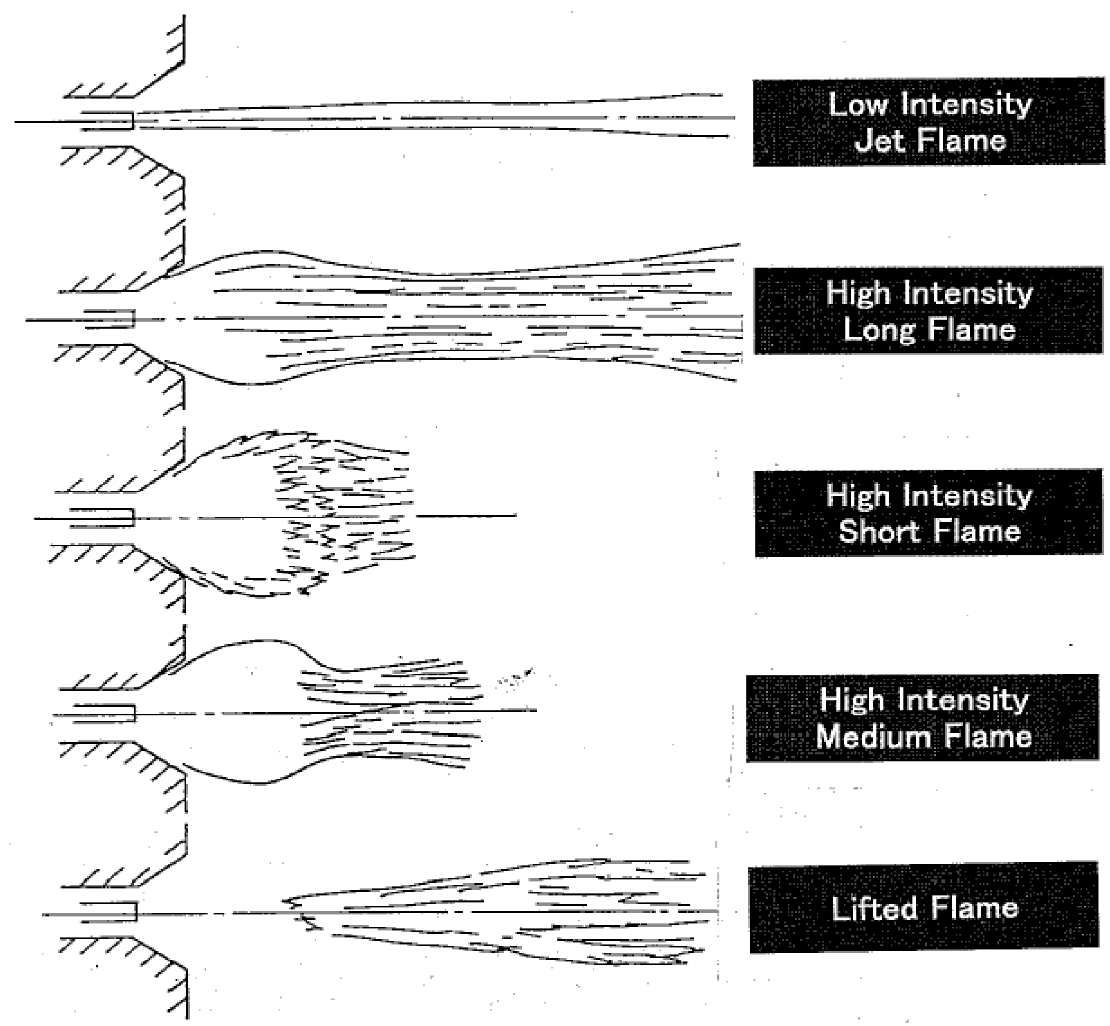


Rotary cup oil atomiser

Classification by atomizing Method Low Pressure Air



Proportioning low pressure oil burner (Model:PLB)



Simple Flame Classification Scheme

New Combustion Technology

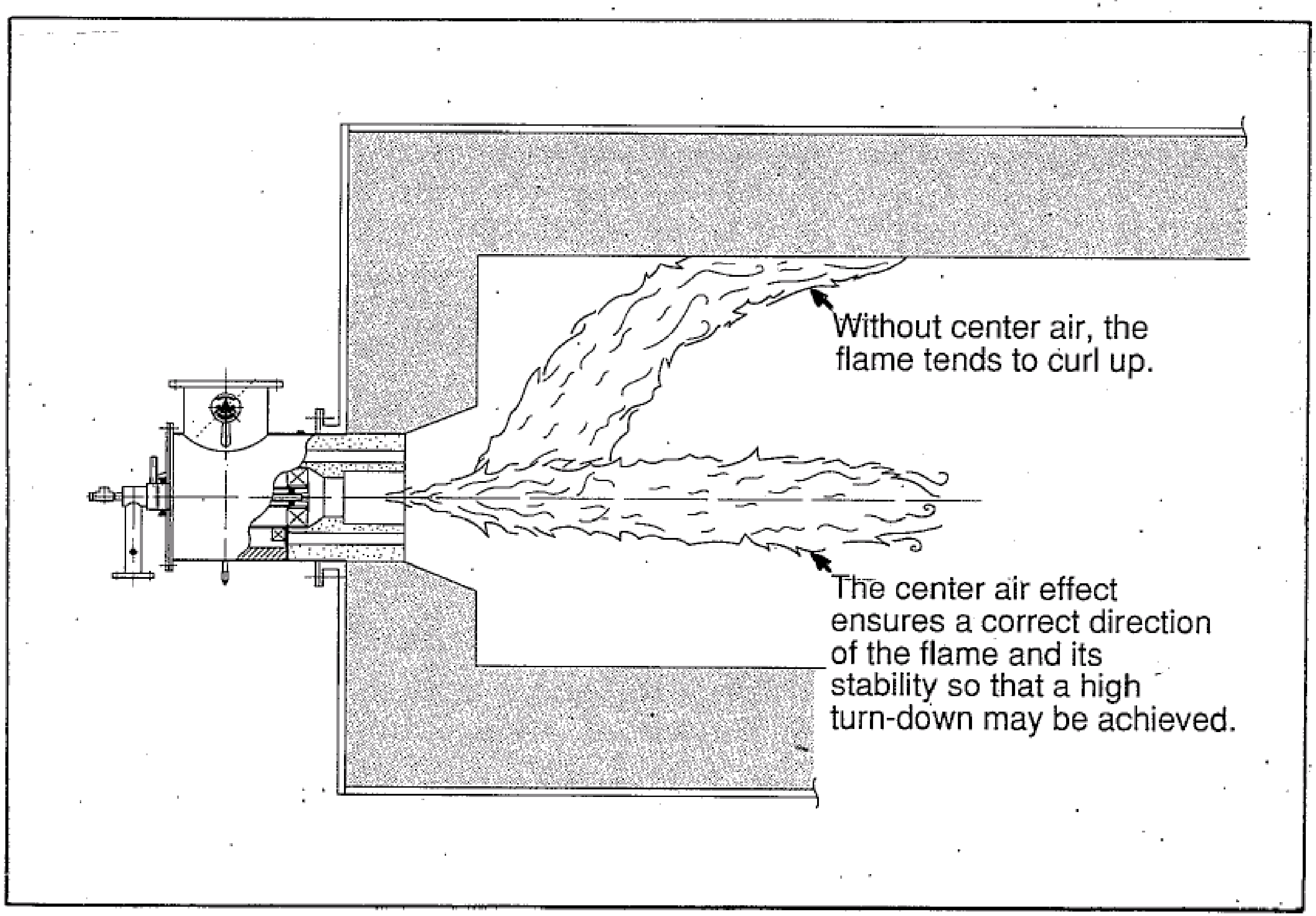
- Luminous Flame Gas Combustion
- **<u>High Turn Down Combustion</u>**
- Combustion of Low Calorific Value Fuel
- Pulse Combustion
- Reducing Combustion
- Fluidized Bed Combustion
- **<u>Oxygen Enriched Combustion</u>**

New Combustion Technology

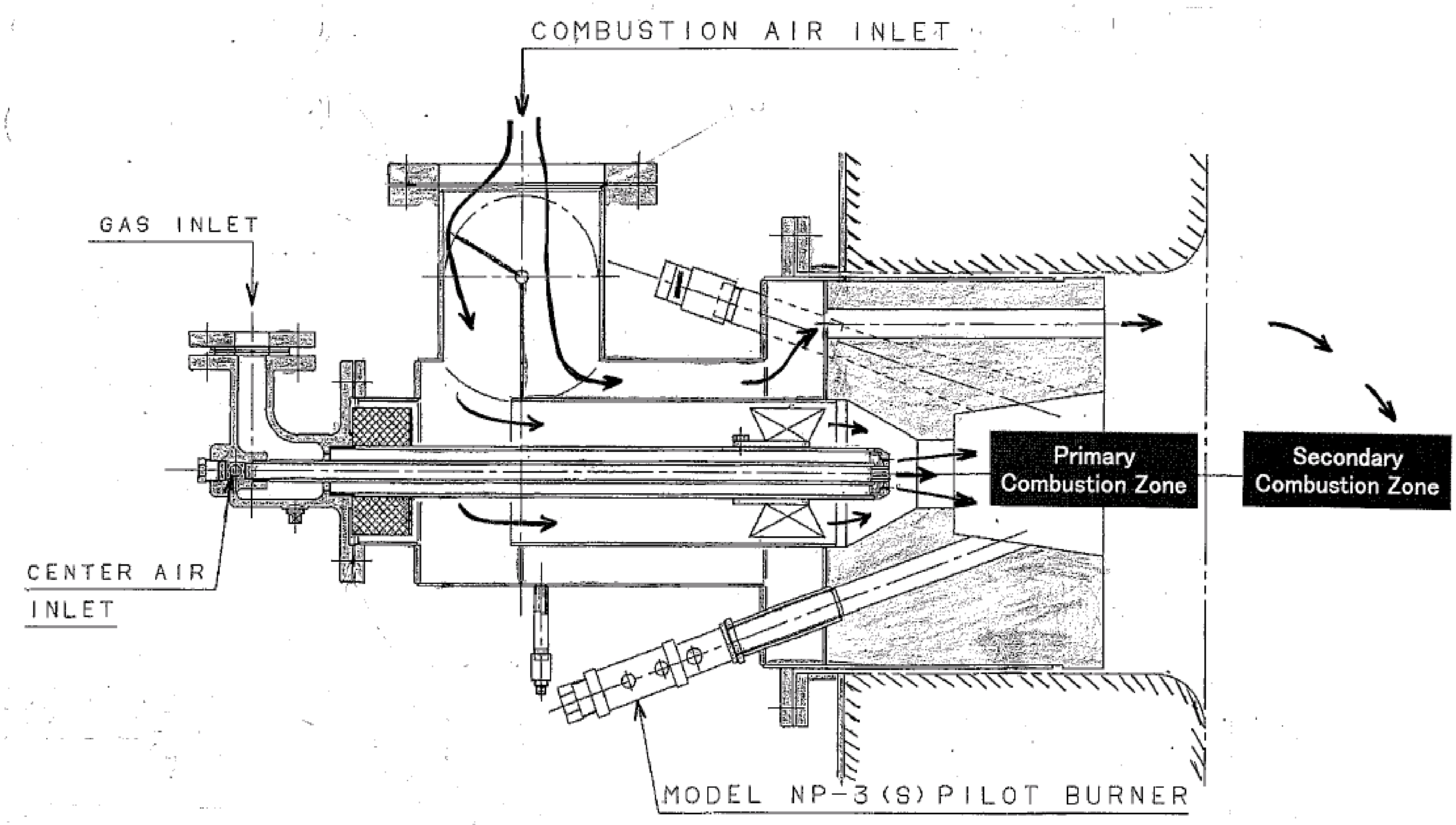
- ☞ Oxygen Deficient Combustion
- ☞ Coal Slurry
- ☞ Oil Residue
- ☞ Waste Products
- ☞ Blacking Technique
- ☞ Intelligent Burner System
- ☞ **Regenerative Burner**
- ☞ **Computational Simulation of Combustion**

New Combustion Technology (1)
High Turn Down Combustion

- T/D Ratio of Conventional Gas Burner ---- 1 : 5
- T/D Ratio of High Turn Down Burner ----- 1 : 10
- Type FHC Burner
  - High Turn Down Low NOx Burner
  - Center Air for improvement of Flame Direction
- Type DGB Burner
  - High Turn Down Burner ---- 1 : 20
  - Burner for Drying Oven in Automobile Production



Center Air Effect



Type FHC High Turn Down Low NOx Burner

New Combustion Technology (2)

Oxygen Enriched Combustion

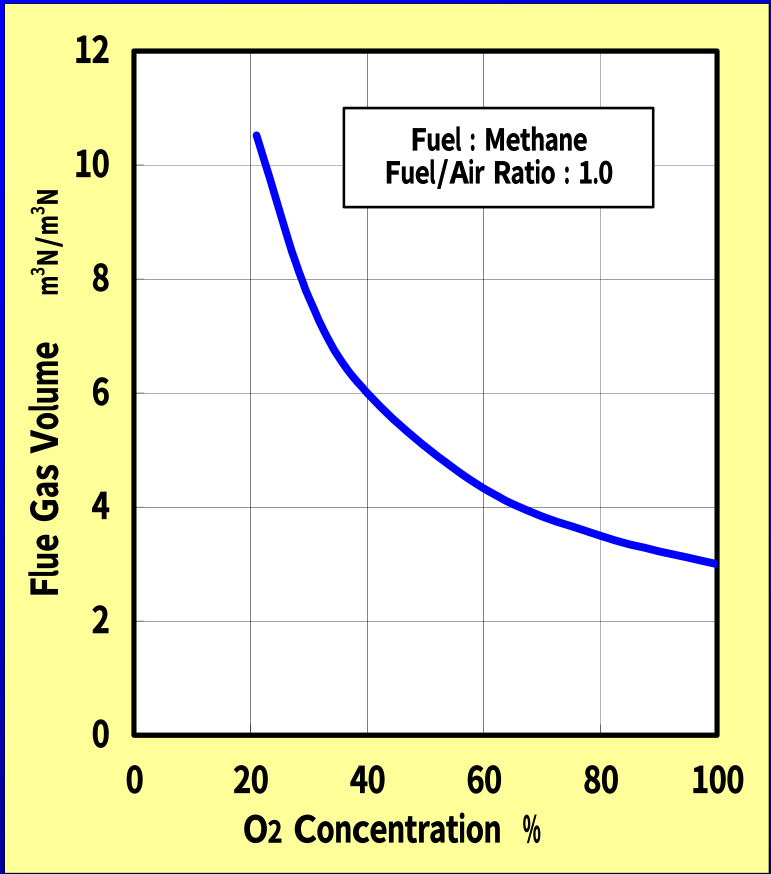
- Composition of Air : O_2 = 21 vol% N_2 = 78 vol%
- Advantages over Ambient Air
  - More elevated flame temp is achievable.
  - Air requirement in volume is less.
  - Flue gas volume is less.
- Disadvantage over Ambient Air
  - Short service life of refractory
  - Relatively High NO_x Emission

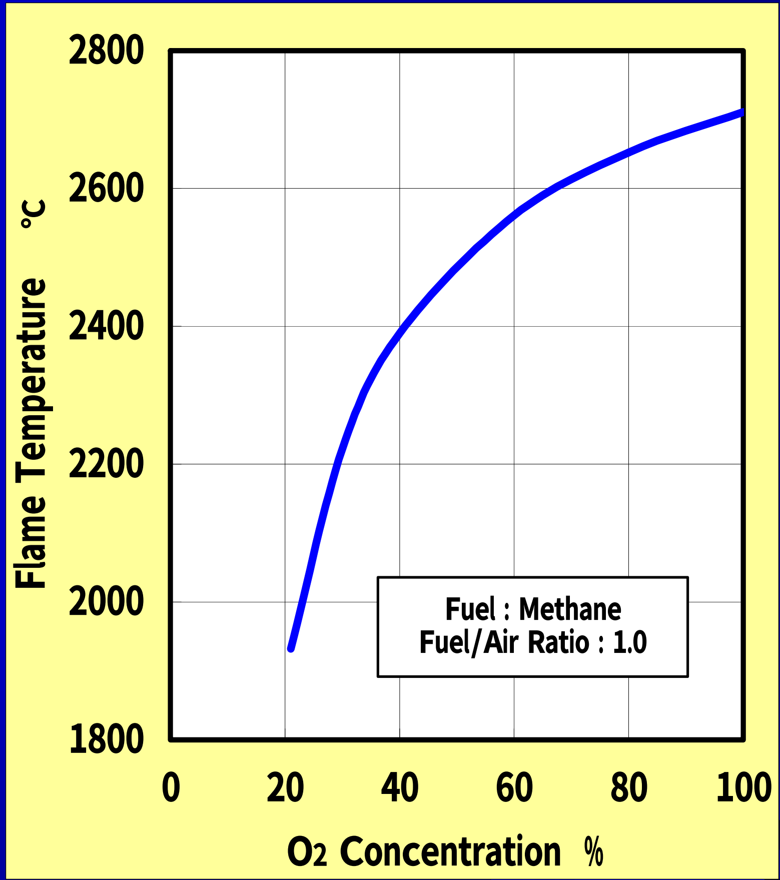
Composition	N_2	O_2	Ar	CO_2	Ne	He	Total
Volume %	78.09	20.95	0.930	0.030	0.002	0.001	100.00
Weight %	75.52	23.15	1.280	0.046	0.001	0.000	100.00

Table 4. Composition of Air (on Sea-level Ground)

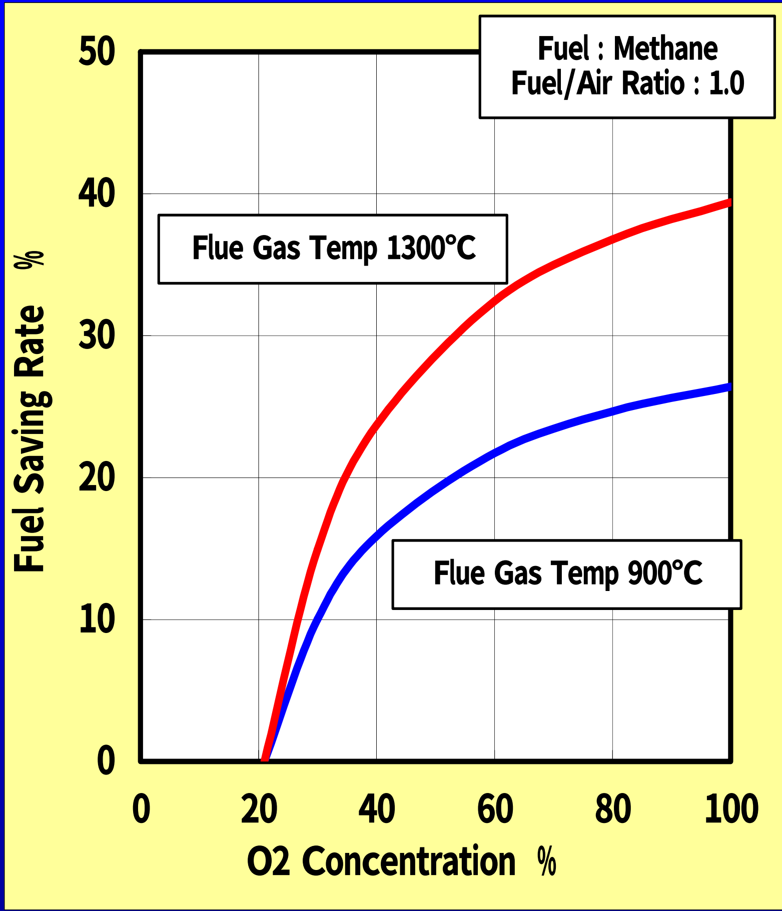
Oxygen Concentration in Comburent	Theoretical Comburent Volume	Theoretical Combustion Product $m^3{}_N/m^3{}_N$				Theoretical Flame Temperature
	$m^3{}_N/m^3{}_N$	CO_2	H_2O	N_2	Total	℃
100%	**2.00**	**1.00**	**2.00**	**0.00**	**3.00**	**2711**
80%	2.50	1.00	2.00	0.50	3.50	2652
60%	3.33	1.00	2.00	1.33	4.33	2561
50%	**4.00**	**1.00**	**2.00**	**2.00**	**5.00**	**2492**
40%	5.00	1.00	2.00	3.00	6.00	2390
30%	6.67	1.00	2.00	4.67	7.67	2222
27%	7.41	1.00	2.00	5.41	8.41	2147
25%	8.00	1.00	2.00	6.00	9.00	2087
23%	8.70	1.00	2.00	6.70	9.70	2016
21%	**9.52**	**1.00**	**2.00**	**7.52**	**10.52**	**1932**
18%	11.11	1.00	2.00	9.11	12.11	1775
12%	16.67	1.00	2.00	14.67	17.67	1335

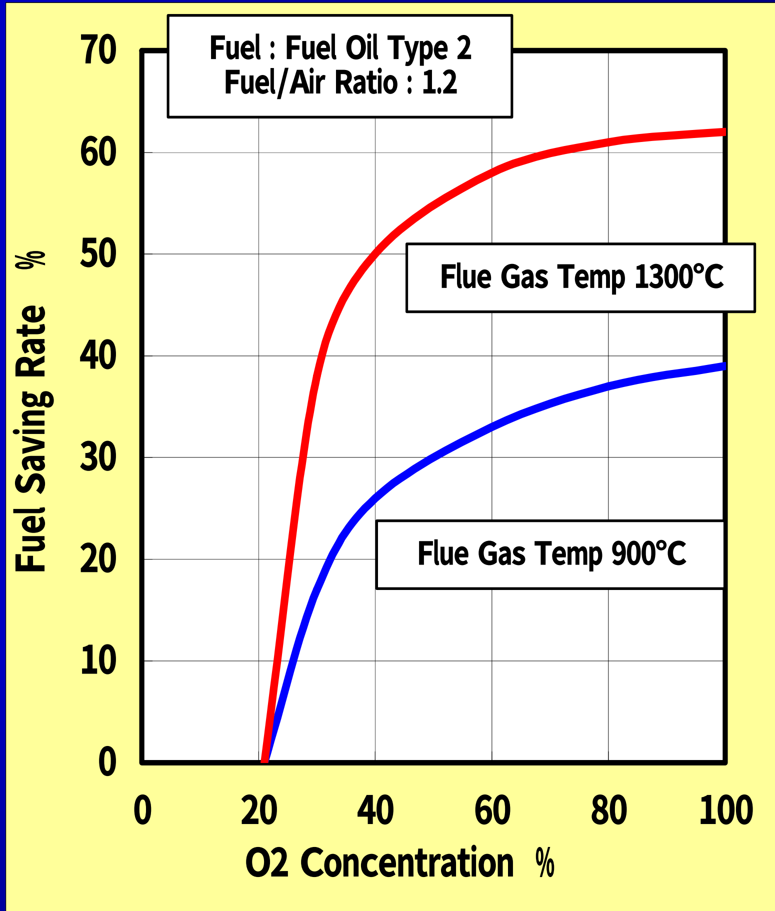
Table 5. Theoretical Combustion Characteristics of Methane in case of Changes in Oxygen Concentration





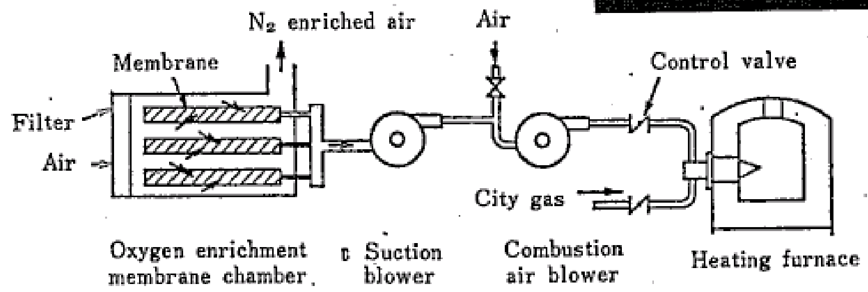
Theoretical Combustion Characteristics of Methane in case of Changes in Oxygen Concentration





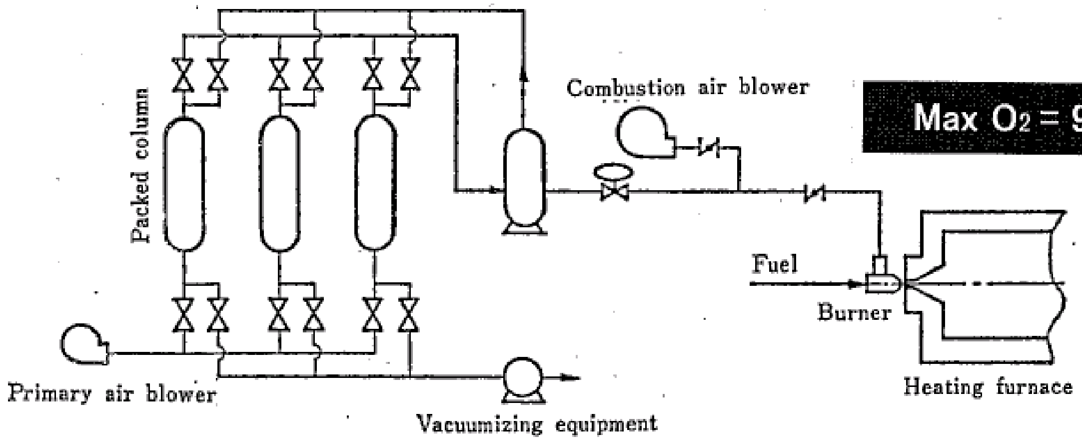
Fuel Saving Rate of Methane & Fuel Oil Type2 in case of Changes in Oxygen Concentration

Max O_2 = 40%



Membrane Method Oxygen Generator

Max O_2 = 95%



Pressure Swing Adsorption (PSA) Oxygen Generator

New Combustion Technology (3)

Regenerative Burner

☞ Advantages

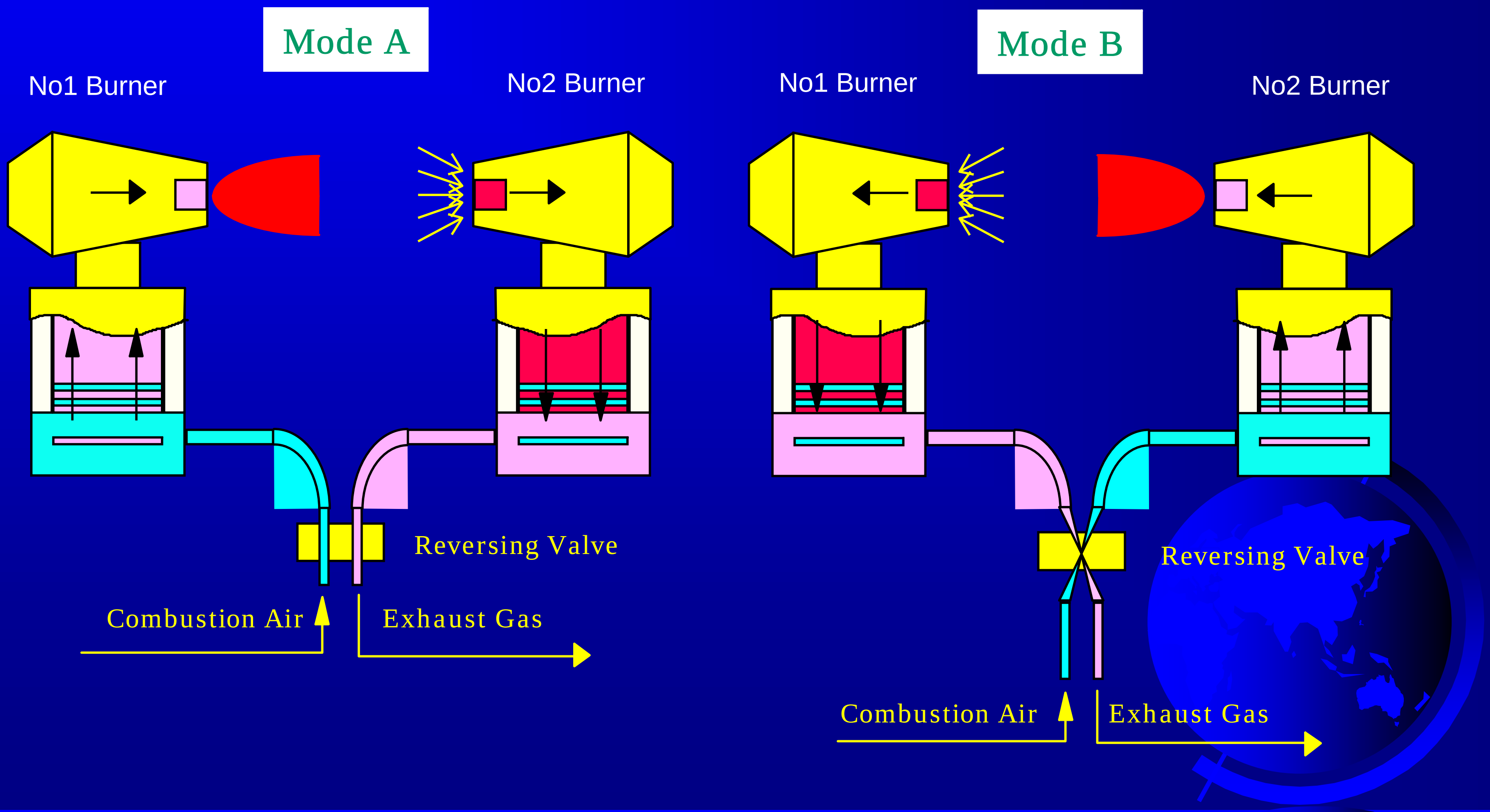
- Waste Gas Heat Recovery Max 90%

  Waste Gas Temp. : 1200℃

  Max. Preheated Air Temp. : 1080℃
- Pulse Firing for Uniform Temp. Distribution
- Heat Exchange in the Burners
- Shorter Furnace Length

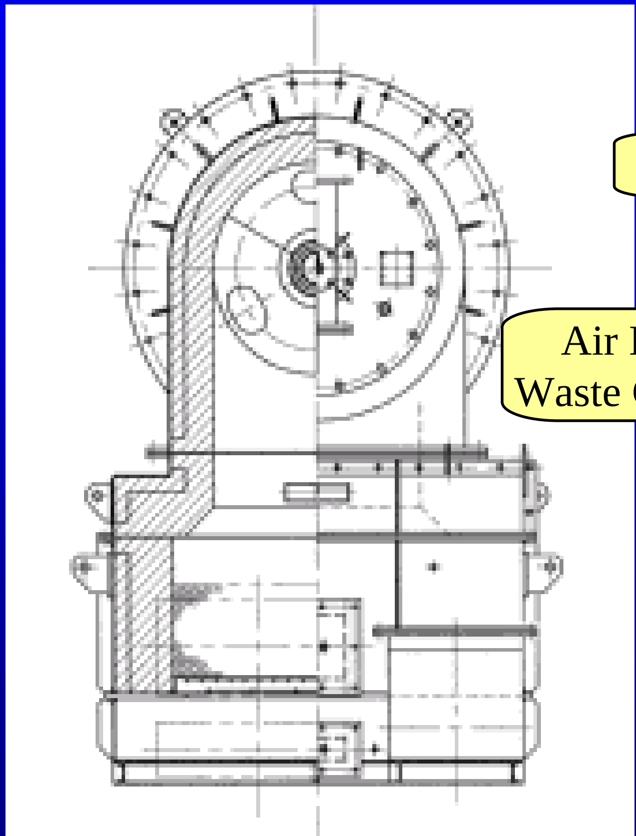
New Combustion Technology (3)

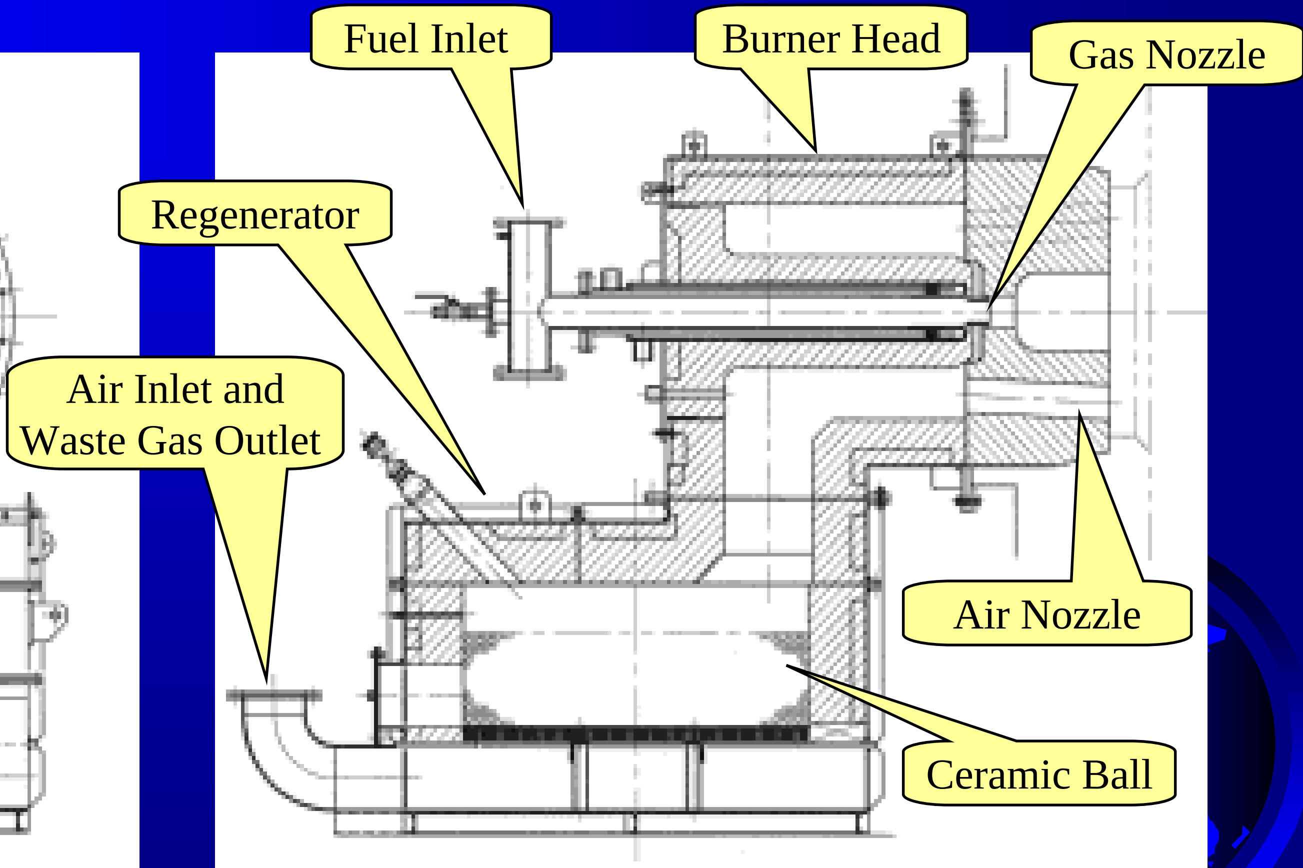
Control Logic of Regenerative Burner



New Combustion Technology (3)

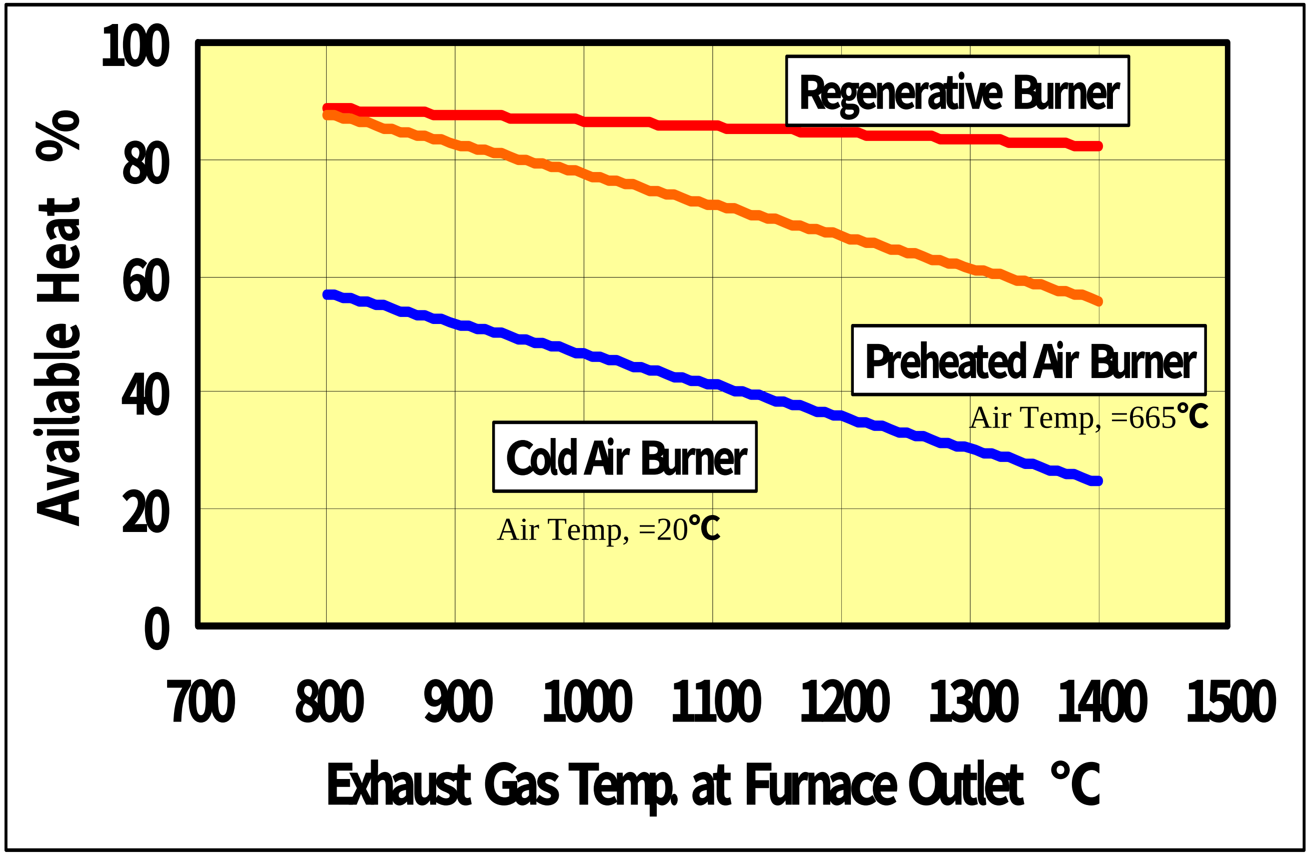
Typical Regenerative Burner Design





New Combustion Technology (3)

Regenerative Burner : Energy Saving Performance

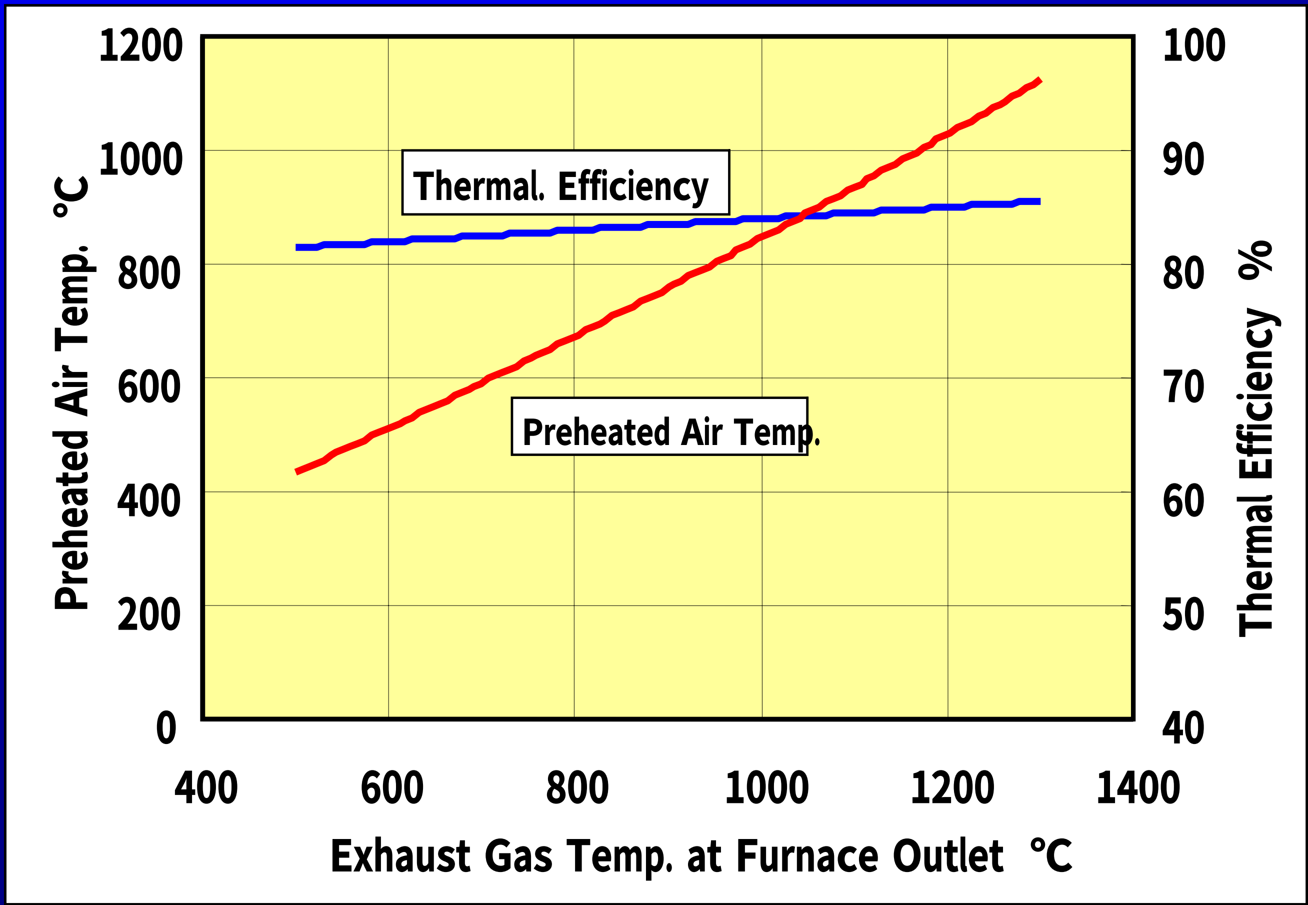


- Fuel : Natural Gas
- Air Ratio : 1.10
- Exhaust Gas Suction Rate : 80%
- Exhaust Gas Temp. at Regenerator Outlet : 120 ℃

New Combustion Technology (3)

Regenerative Burner

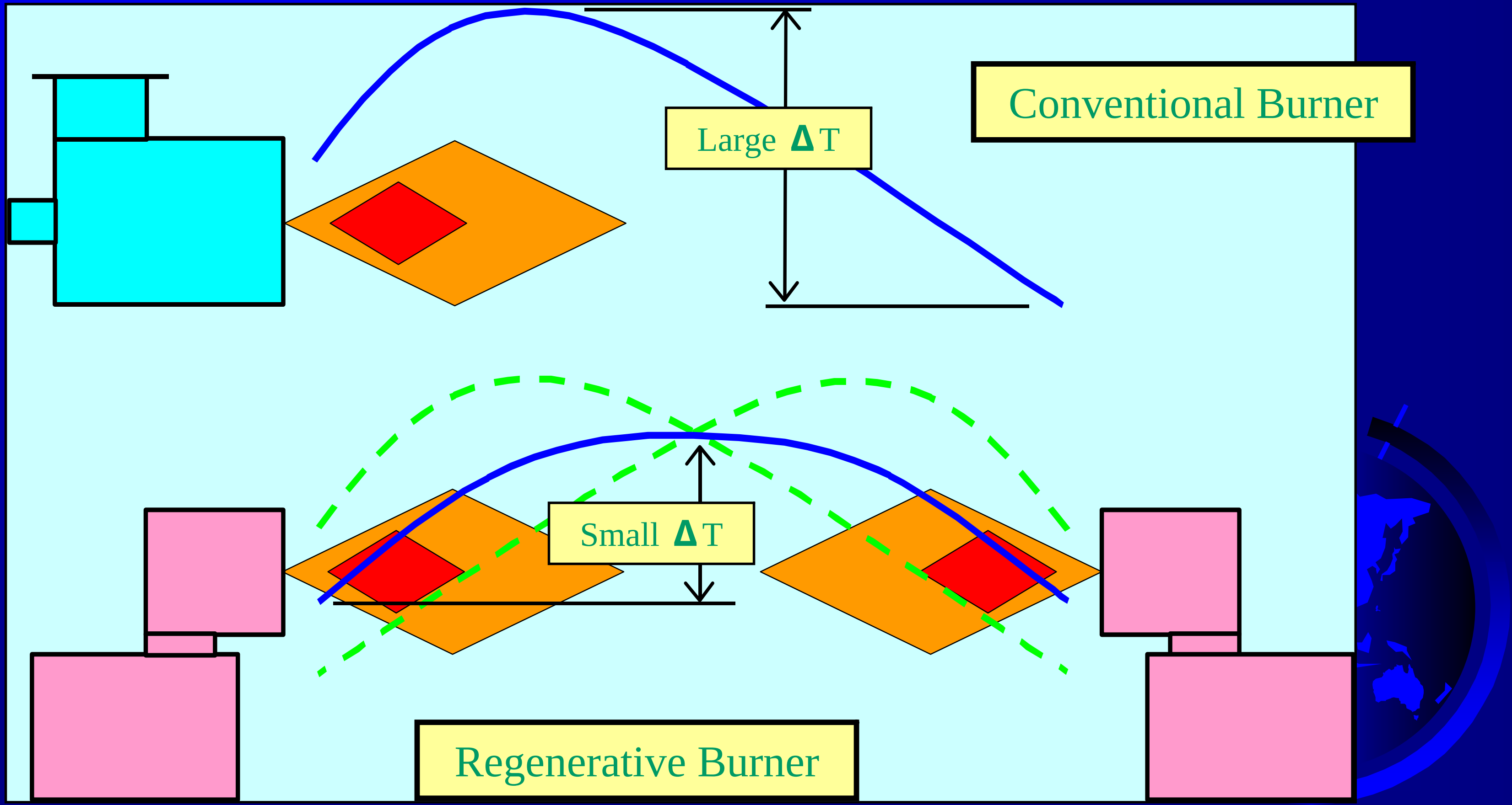
Preheat Air Temp. and Thermal Efficiency



- ❖ Fuel : Natural Gas
- ❖ Air Ratio : 1.10
- ❖ Exhaust Gas Suction Rate : 80%
- ❖ Exhaust Gas Temp. at Regenerator Outlet : 120 ℃

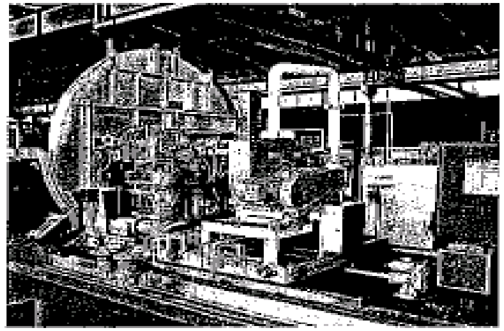
New Combustion Technology (3)

Regenerative Burner : Temperature Uniformity

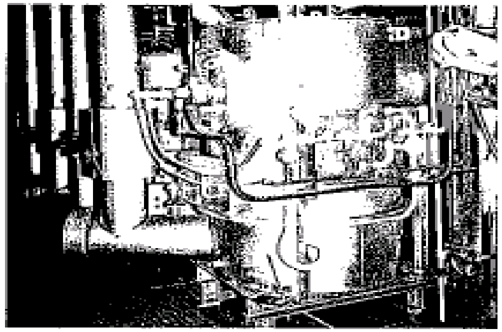


New Combustion Technology (3)

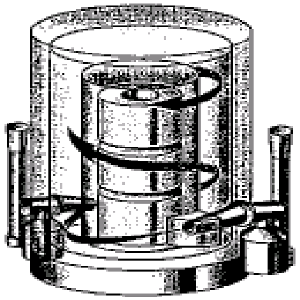
Application Examples of Regenerative Burner



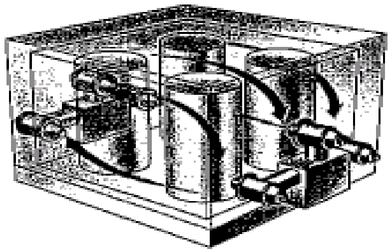
RCB regenerative burners fitted to a ladle preheater



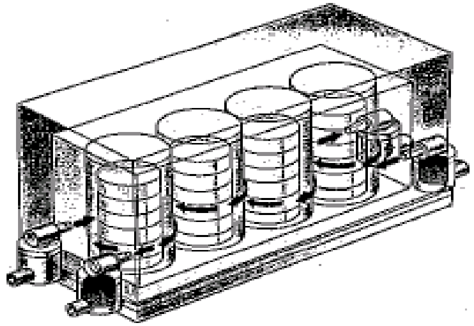
RCB regenerative burners fitted to a steel reheating furnace



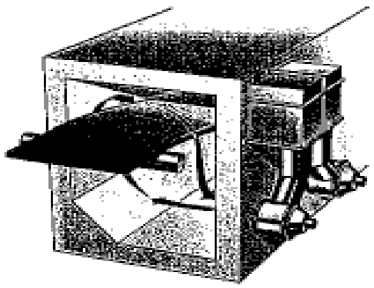
Ball type coil annealing furnace



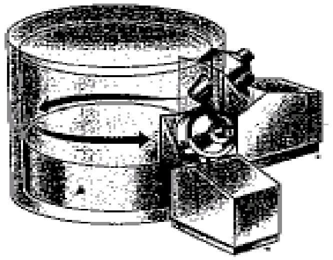
Cross fired coil annealing furnace



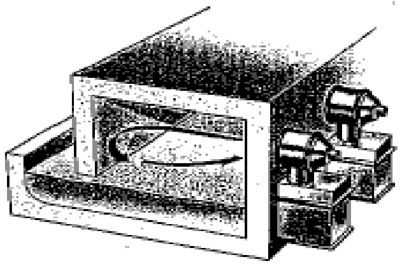
Corner fired coil annealing furnace



Catenary type continuous steel strip heat treating furnace



Round reverberatory aluminum melting furnace



Front well type reverberatory alminum melting furnace

New Combustion Technology (4)

Computational Simulation of Combustion

☞ Analysis Cords

- Fluent, Star-CD, etc...

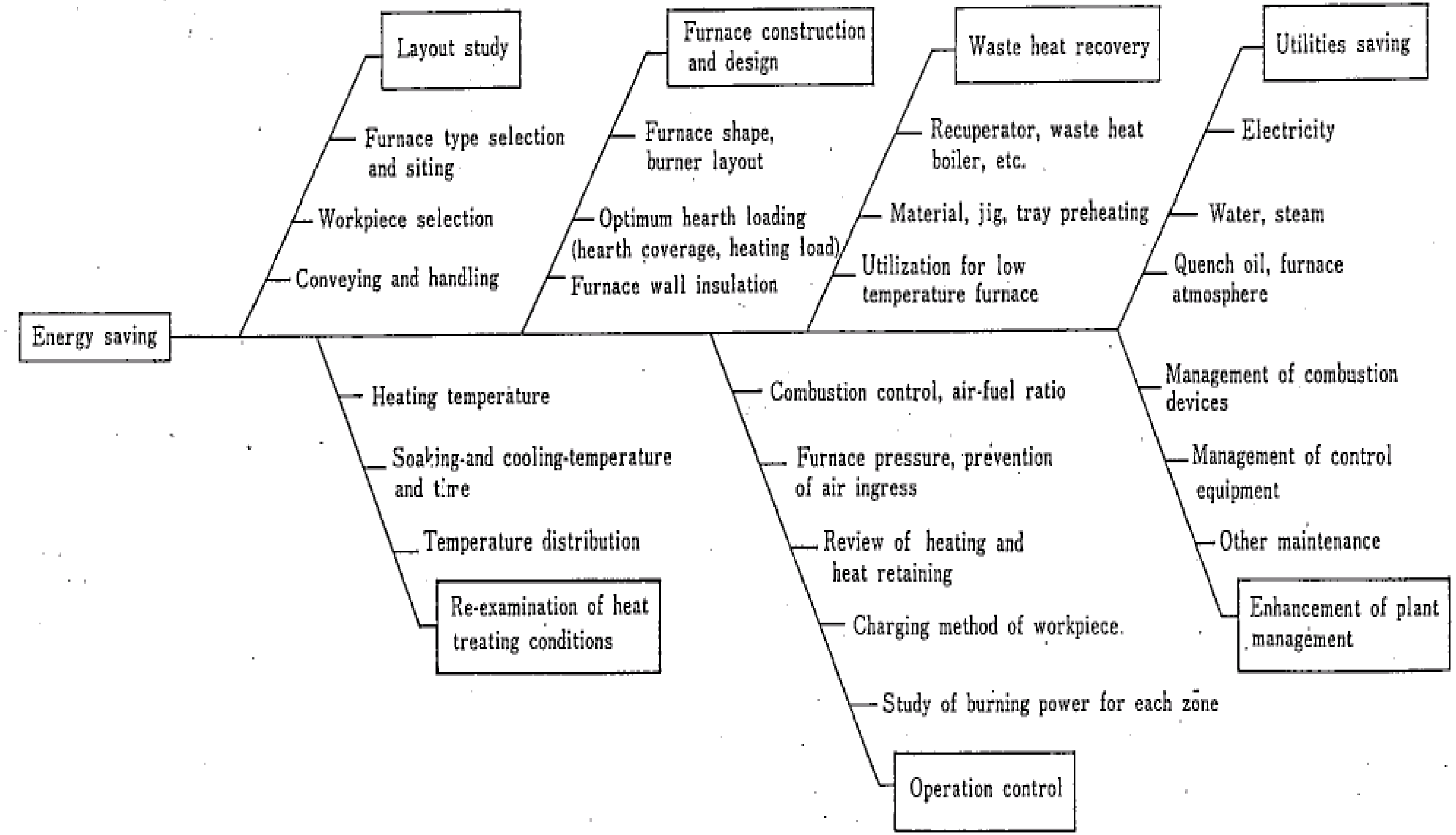
☞ Simulated Results

- Distributions of Fluid Temperature, Fluid Flow and Gas Species.

☞ At present, accuracy of the results is still low. However, in the near future, it will be improved.

Combustion Technology for Energy Saving

- Layout study
- Re-examination of Heat Treating Condition
- Furnace Construction and Design
- Operation Control
- Waste Heat Recovery
- Utilities Saving
- Enhancement of Plant Management



Factor of Energy Saving Measures

Combustion Technology for Energy Saving

--- Excess Air Control ---

☞ Definition of Excess Air Ratio

$$\frac{\text{Actual Combustion Air Flows (m3N/kg-fuel)}}{\text{Theoretical Air Requirement (m3N/kg-fuel)}}$$

ex)
- Flue Gas Temp. = 1300℃
- Excess Air Ratio Change from 1.5 to 1.2
- Fuel Saving Rate = 40.2%

☞ Combined with preheat and excess air technology control is much more effectively.

Furnace Temperature ℃	Air Ratio Before Correction	Air Ratio After Correction				
		1.40	1.30	1.20	1.10	1.00
700	1.50	3.9	7.4	10.7	13.8	16.7
	1.40		3.8	7.3	10.5	13.5
	1.30			3.7	7.0	10.1
	1.20				3.5	6.7
	1.10					3.4
900	1.50	6.2	11.7	16.6	21.0	25.0
	1.40		5.9	11.3	16.0	20.2
	1.30			5.7	10.7	15.2
	1.20				5.3	10.1
	1.10					5.1
1100	1.50	10.3	18.6	25.6	31.4	36.4
	1.40		9.4	17.3	23.8	29.4
	1.30			8.7	15.9	22.1
	1.20				7.9	14.7
	1.10					7.4
1300	1.50	18.3	31.0	40.2	47.3	52.9
	1.40		15.7	27.2	35.9	42.7
	1.30			13.7	23.9	32.1
	1.20				11.9	21.3
	1.10					10.7

Table 6. Fuel Saving Rate (%) on Excess Air Control (Fuel Oil Type 1)

Combustion Technology for Energy Saving

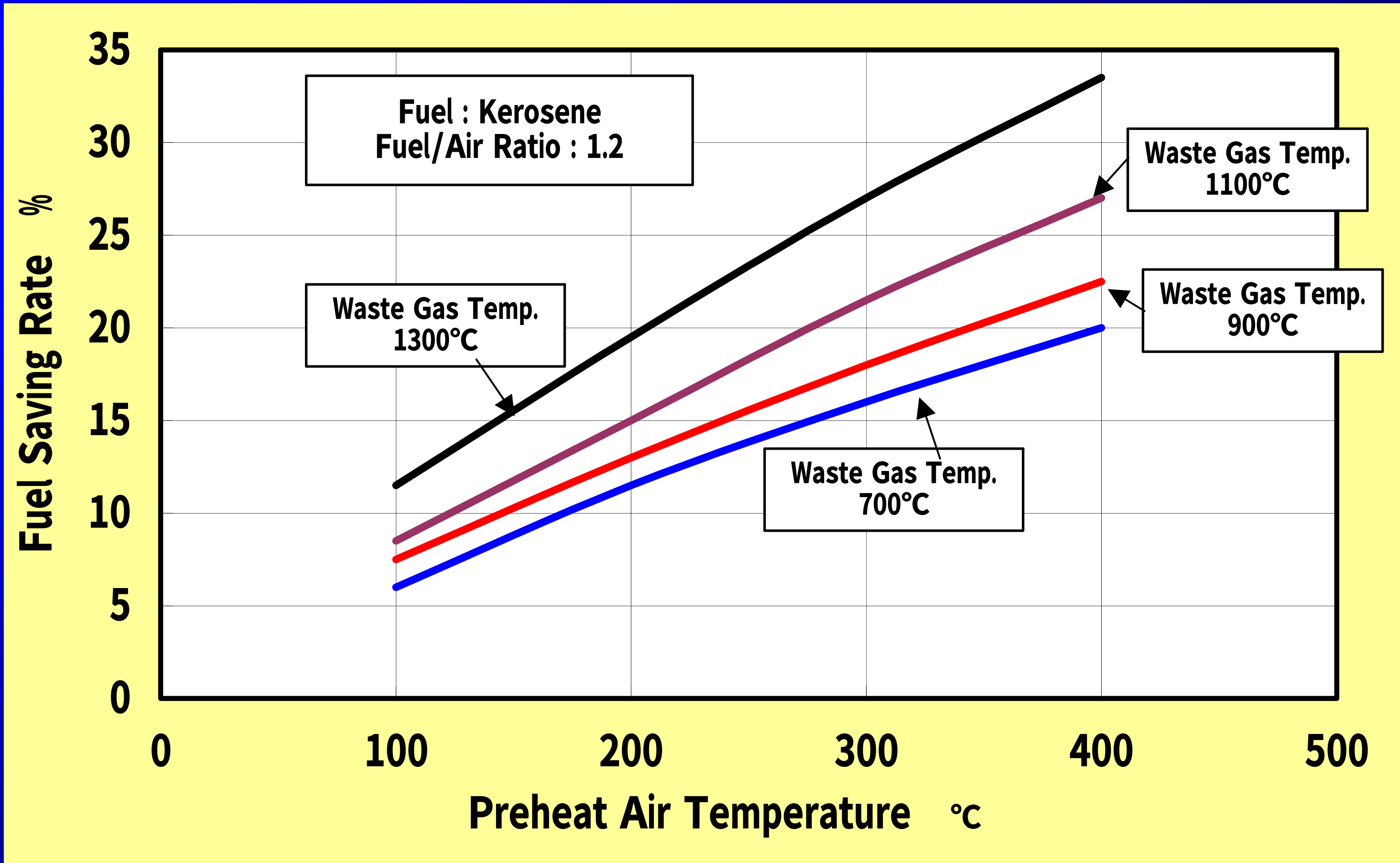
--- Heat Recovery from Flue Gas ---

- Outline of Air Preheater
  - Recuperator and Regenerator
- Fuel saving rate depends on preheated air temperature and exhaust gas temperature.

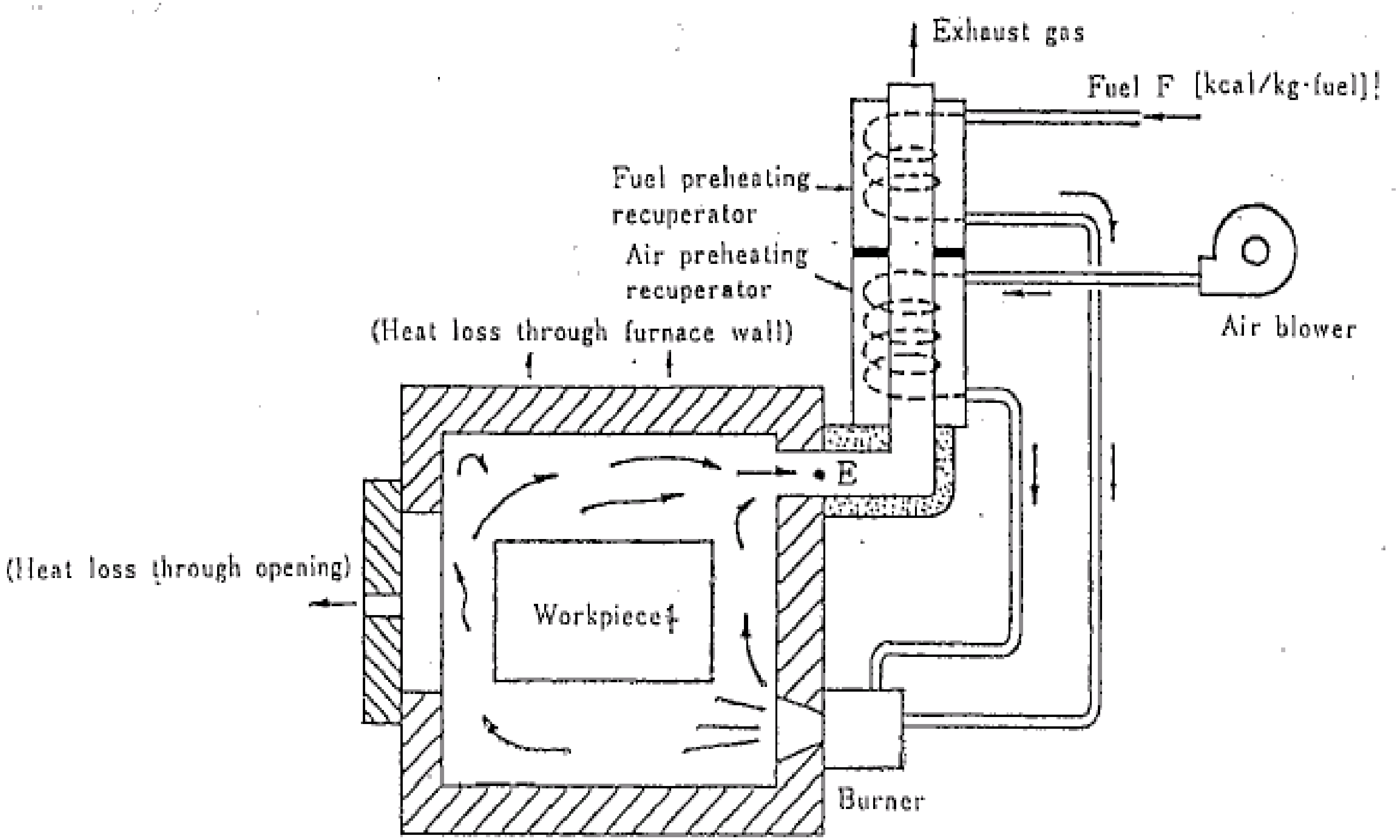
ex)
- Kerosene, Excess Air Ratio=1.2
- Flue Gas and Preheated Air Temp. = 900 and 300℃
- Fuel Saving Rate = 18.4%

Type				Exhaust Gas Temp. Limit	Preheated Air Temp.	Applied Furnace
Recuperator	Metallic	Flue Type	Convection type Multi-tube Type	1000°C Max	300〜600°C	Reheating Furnace Heat Treating Furnace Other Industrial Furnace
		Chimney Type	Radiation Type Radiation+Convection Type	1000〜1300°C		
	Ceramic (Tile)		Armco Type Stein Type	1200〜1400°C	400〜700°C	Soaking Furnace Glass Oven
Regenerator	Conventional Type			1000〜1600°C	600〜1300°C	Coke Oven Hot Blast Furnace Glass Oven (Melter)
	Rotary Regenerating Type			600°C Max	100〜300°C	Boiler Hot Blast Furnace Oil Refinery Furnace
	Regenerative Burner Type			1000〜1300°C	900〜1200°C	Reheating Furnace Heat Treating Furnace Other Industrial Furnace

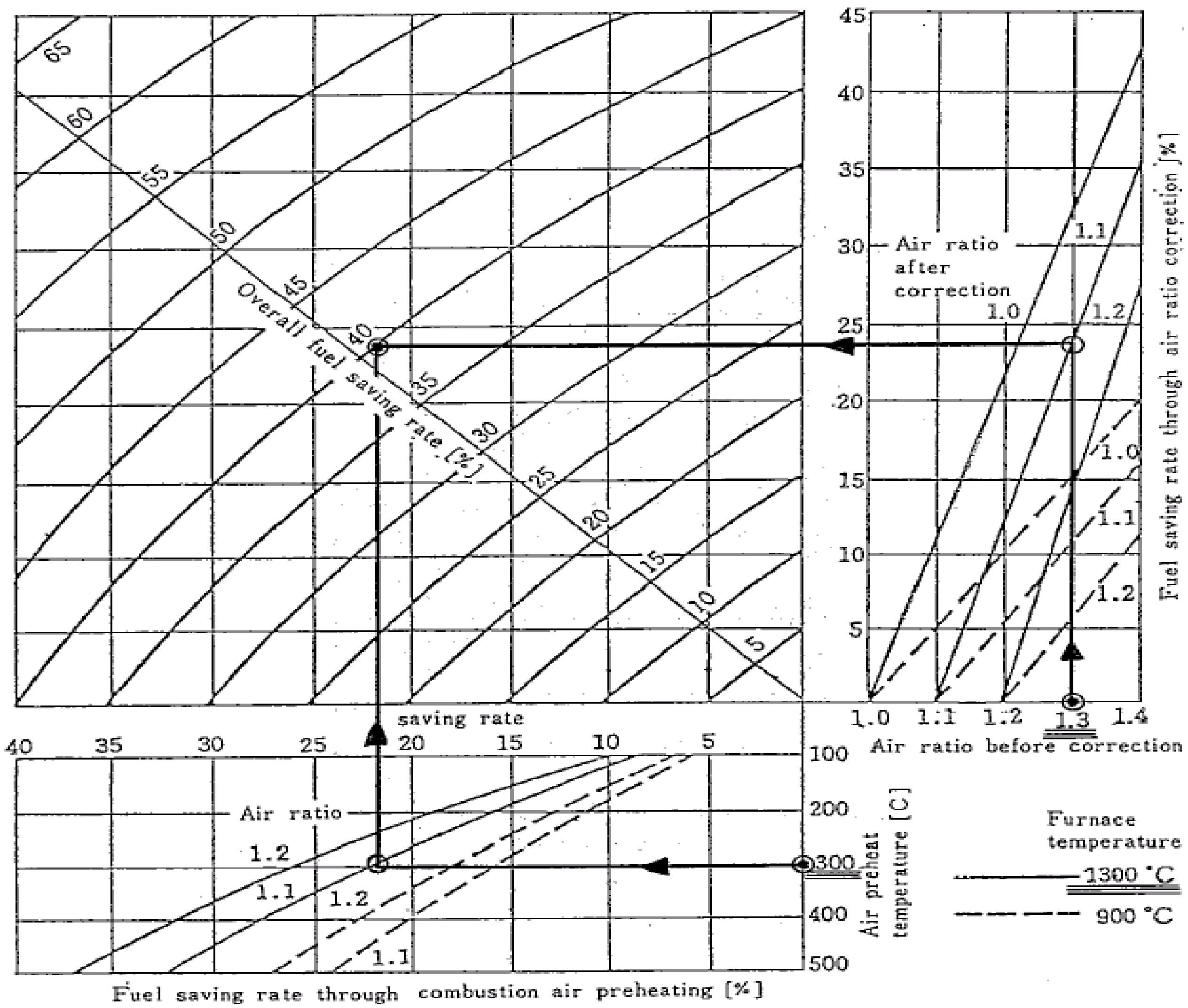
Table 7. Outline of Air Preheater



Fuel Saving Rate through Air Preheating



Basic Conceptual Diagram of Waste Heat Utilization



Overall Fuel Saving Rate through Combustion Air Preheating and Air Ratio Correction (Fuel Oil Type 2)

Combustion Technology for Low Environmental Pollution

☞ Classification of NOx

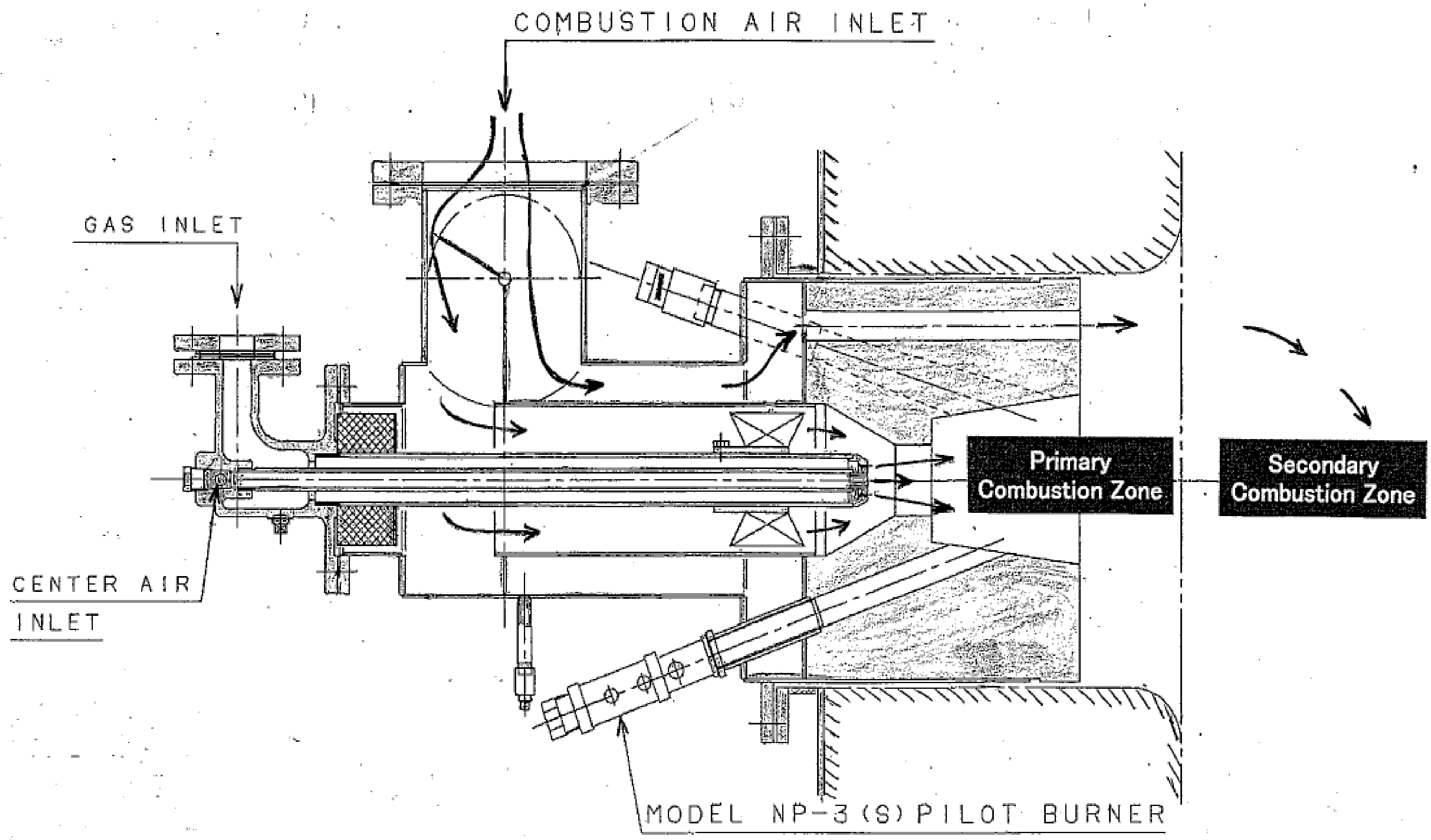
- Thermal NOx is generated when atmospheric N2 is heated to high temperatures. Their generation mechanisms include Zeldovich
- Prompt NO mechanism is specific to the combustion of hydrocarbon fuels.
- Fuel NOx is generated from nitrogen compounds in fuel, such as quinoline and pyridine in petroleum-based fuels and coal.

Combustion Technology for Low Environmental Pollution

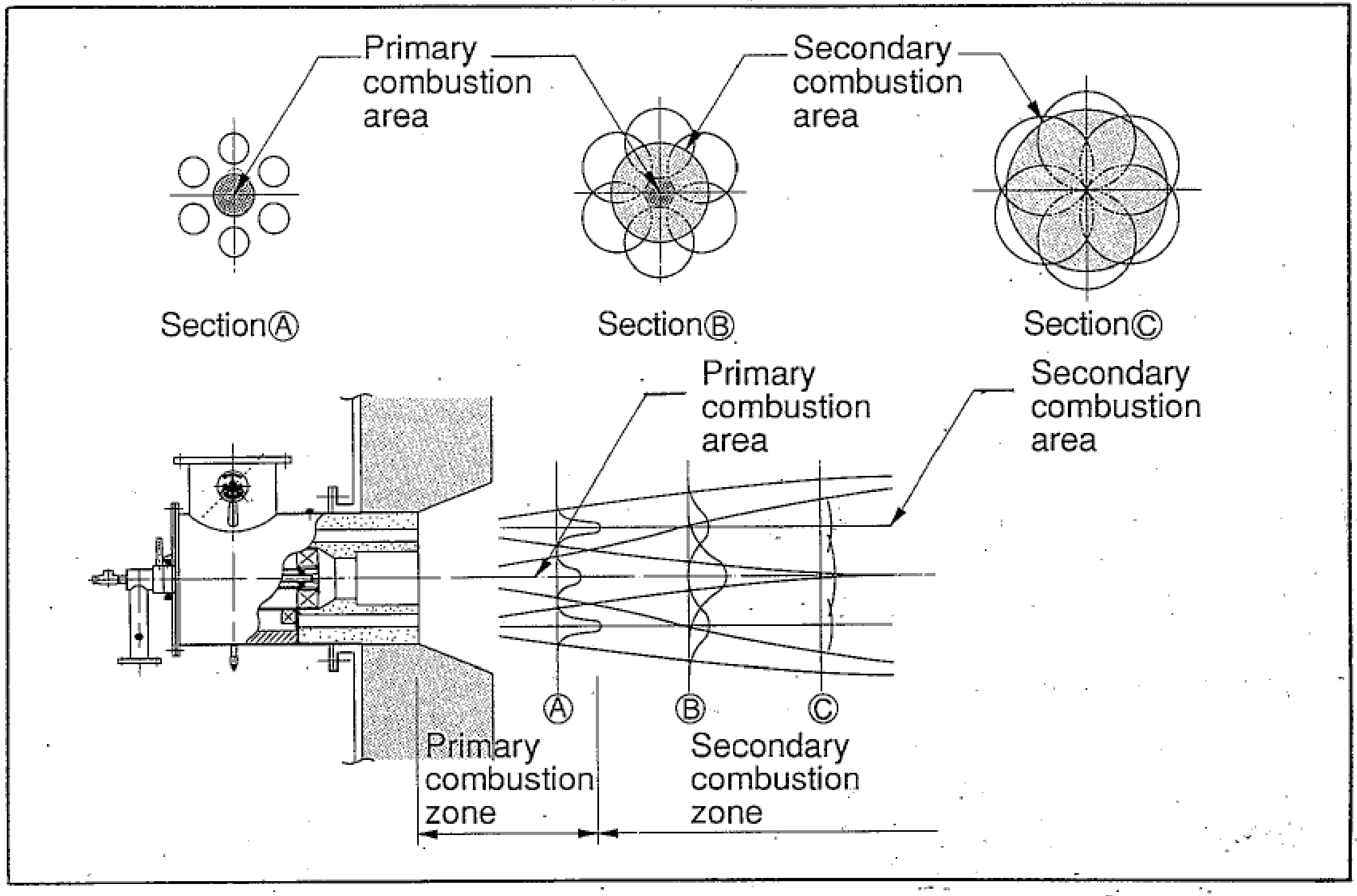
- Impact of NOx

  NO2 turn into photochemical oxidants, thereby giving rise to photochemical smog.

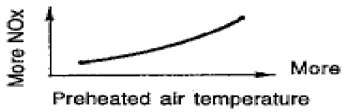
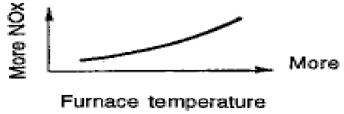
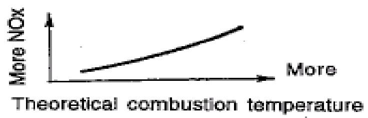
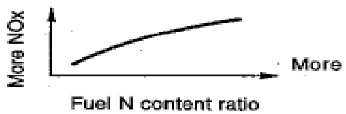
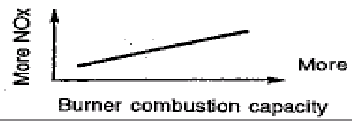
- NOx reduction measures
  - Combustion control
  - Use of low NOx burners
  - Modification of combustion process
  - Denitrification equipment



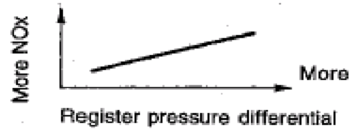
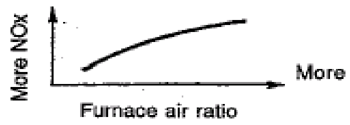
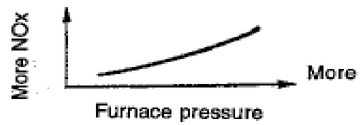
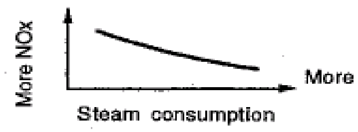
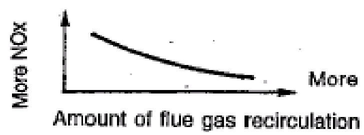
Type FHC High Turn Down Low NOx Burner



NOx Reduction Method on FHC Burner

No.	Operation parameter	Chart of NOx variation pattern	Remarks
1	Burner air ratio		Burner air ratio: when large, NOx → large (O_2 partial pressure of flame → large) If it further increases, NOx → small (Fall in flame temperature)
2	Preheated air temperature		Preheated air temperature: when large, NOx → large (Rise in flame temperature)
3	Furnace temperature		Furnace temperature: when large, NOx → large (Rise in flame temperature)
4	Furnace liberation rate (Furnace cross section liberation rate or furnace volume liberation rate)		Furnace liberation rate: when large, NOx → large (Rise in flame temperature due to small heat dissipation into surroundings)
5	Fuel type		Fuel with large theoretical combustion temperature → more NOx
6	Fuel N content ratio		Fuel N content ratio: large → more NOx
7	Burner combustion capacity		Burner combustion capacity: large → more NOx (Small heat dissipation into surroundings → Rise in flame temperature)

Relationship between Burner Operation Patameters and Amount of NOx Generated (1)

No.	Operation parameter	Chart of NOx variation pattern	Remarks
8	Burner register pressure differential		Burner register pressure differential: large → more NOx (Short flame due to better mixing → rise in flame temperature)
9	Furnace air ratio		Furnace air ratio: large → more NOx (when there is a supply of O_2 from sources other than the burner, such as intruding air) (O_2 partial pressure of flame → large)
10	Furnace pressure		Furnace pressure: large -> more NOx
11	Steam consumption (steam spray or suction)		Steam consumption: large → less NOx (Fall in flame temperature)
12	Amount of flue gas recirculation		Amount of flue gas recirculation: large → less NOx (Decreased O_2 partial pressure of flame → fall in flame temperature)

Relationship between Burner Operation Patameters and Amount of NOx Generated (2)

Combustion Technology for Low Environmental Pollution

☞ Impact of Sox

(1) SO_2 released into the atmosphere causes acid rain and exerts an enormous impact on ecosystems.

(2) Condensed sulfuric acid can corrode a combustion facility.

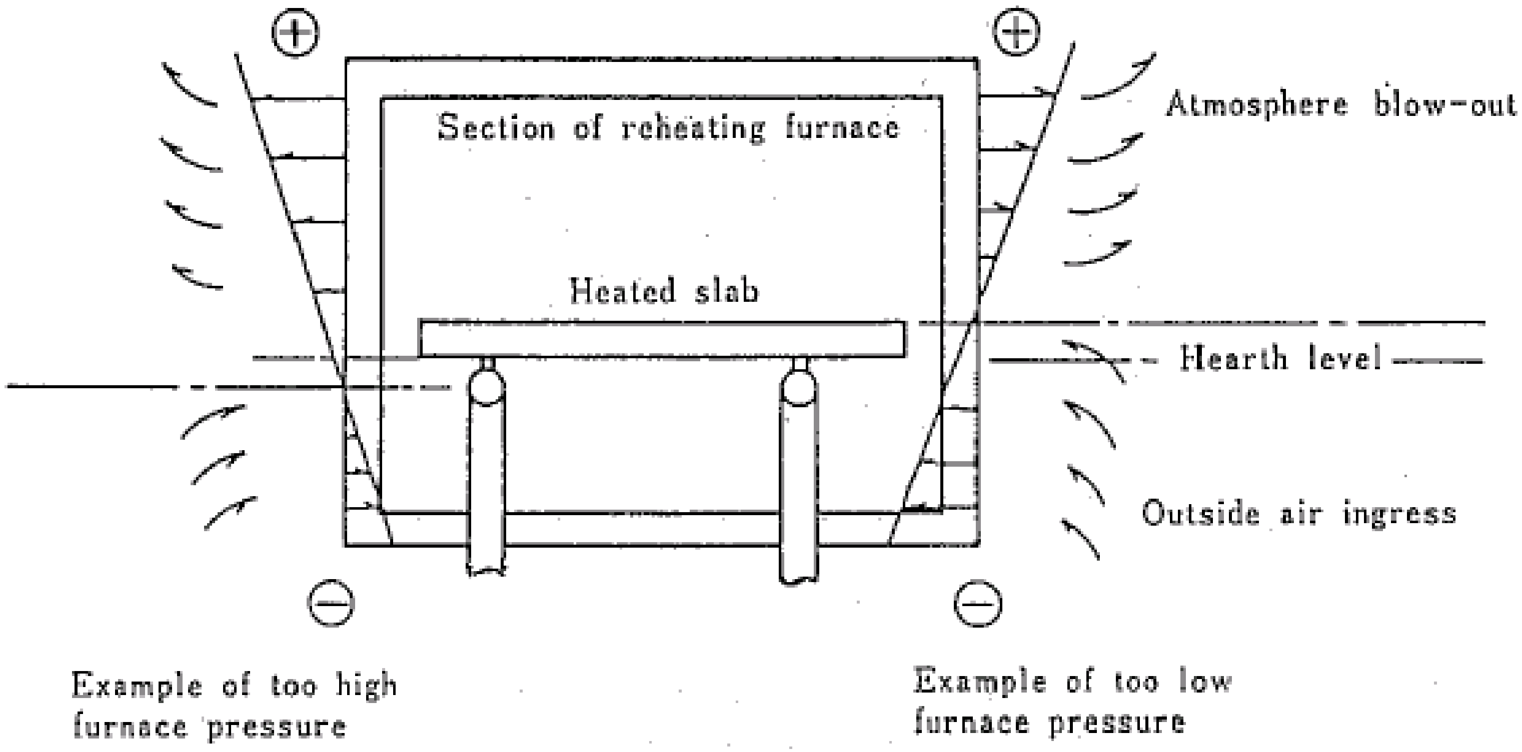
Combustion Technology for Low Environmental Pollution

☞ SOx reduction measures

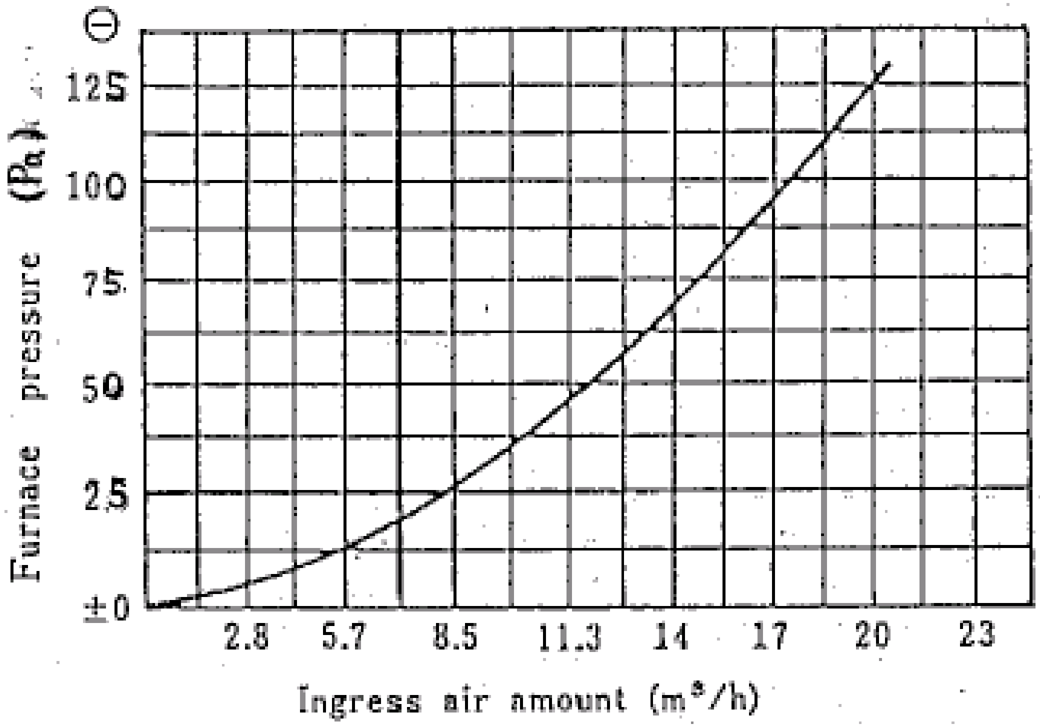
- All combustible sulfur contained in a fuel turns into SOx.
- It is impossible to reduce SOx via combustion technology.
- Switch to Low-sulfur Fuels
- Flue Gas Desulfurization Equipment

Industrial Furnace Conservation Techniques

- Furnace Pressure Control
  - Negative : Adversely Affect to Products Quality and Thermal Efficiency
  - Too High : Hot Combustion Products Tend to Blow Out
- Furnace Design Aspect
  - Effective Furnace Length and Shape
  - Application of Ceramic Fiber to Furnace Wall

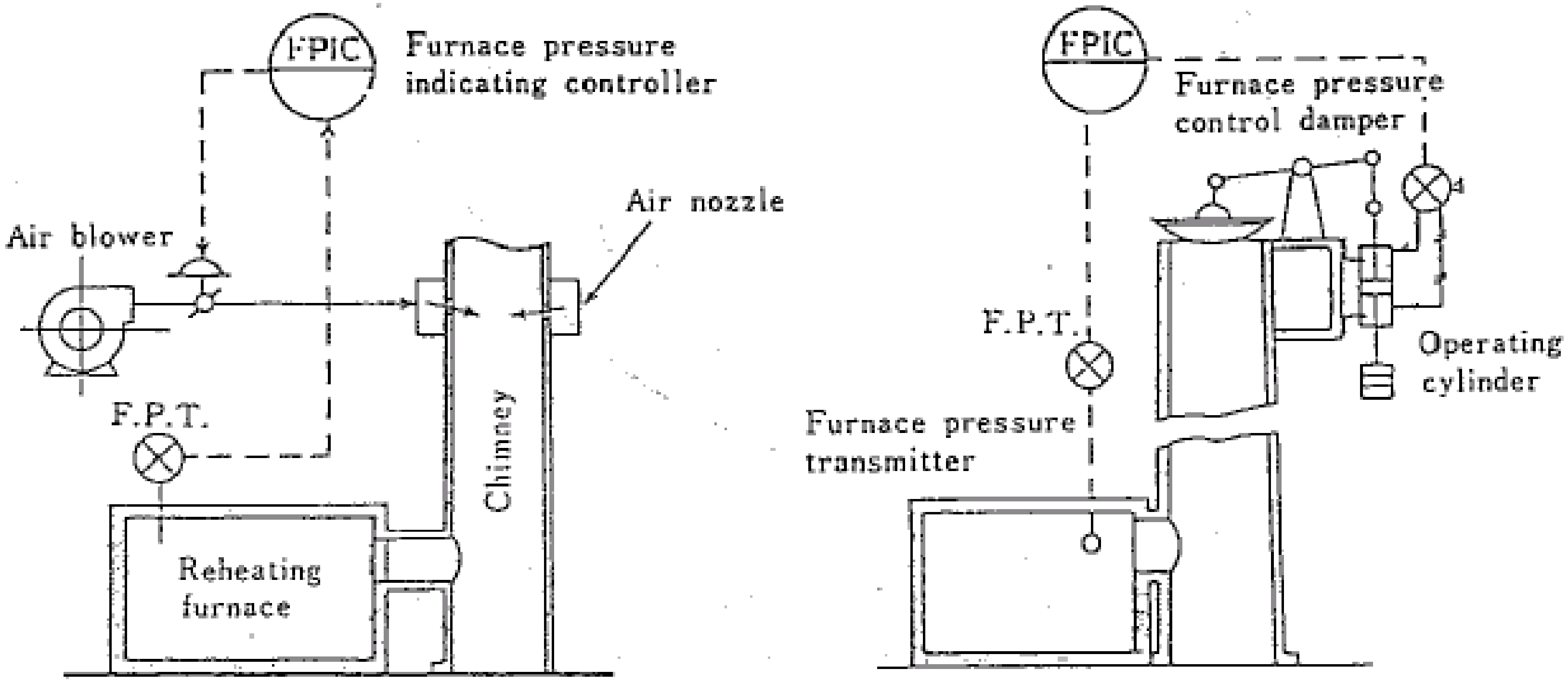


Air Ingress during Reheating Furnace Operation



(Air ingress through 25.4mm square opening)

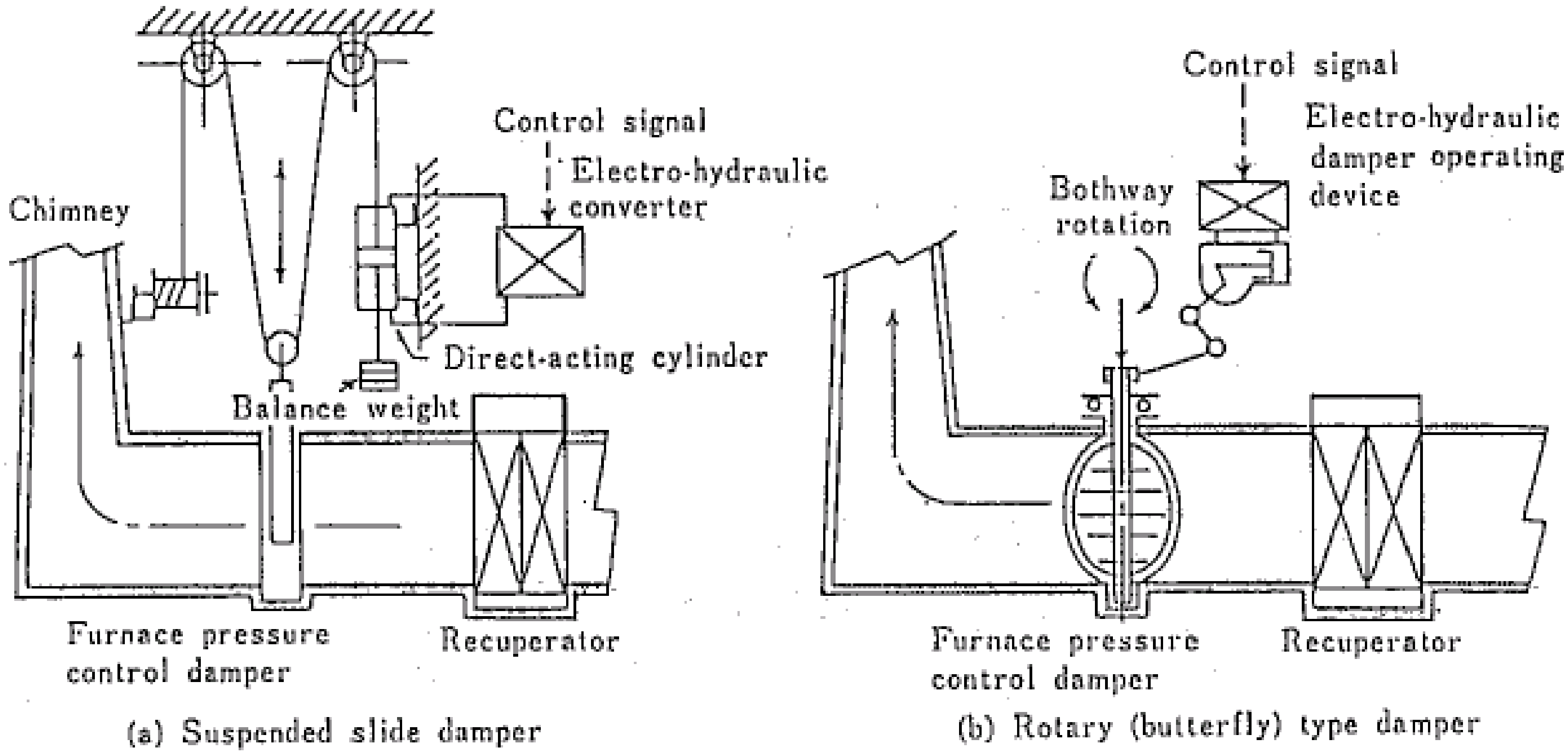
Furnace Pressure vs Ingress Air Amount



(a) Air curtain type

(b) Poppet valve type

Damper for Pressure Control



Damper Configuration

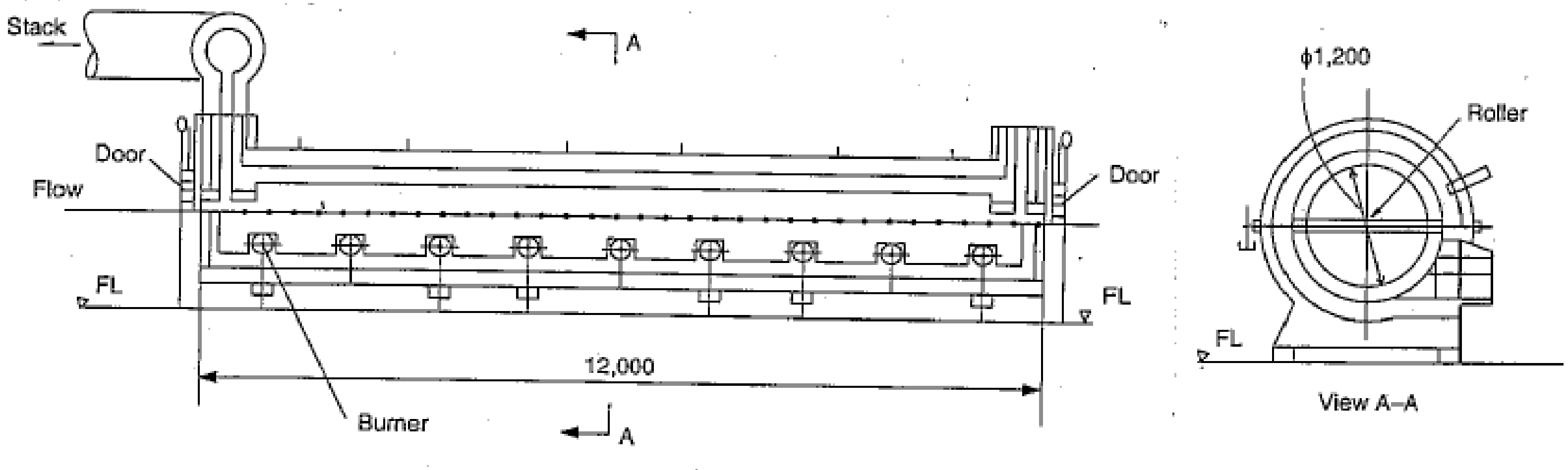
Case Study of ECCJ Factory
How to Save Energy

- Excess Air Reduction
  - Install Flow Control System
- Wall Heat Loss Reduction
  - Enhance Heat Insulation of Furnace Wall
- Exhaust Gas Heat Loss Reduction
  - Install Heat Exchanger at Chimney
- Combination of Above Three Improvements

Heating Furnace

1) Type Roller Hearth Type Bar Heating Furnace for Quenching

2) Dimension

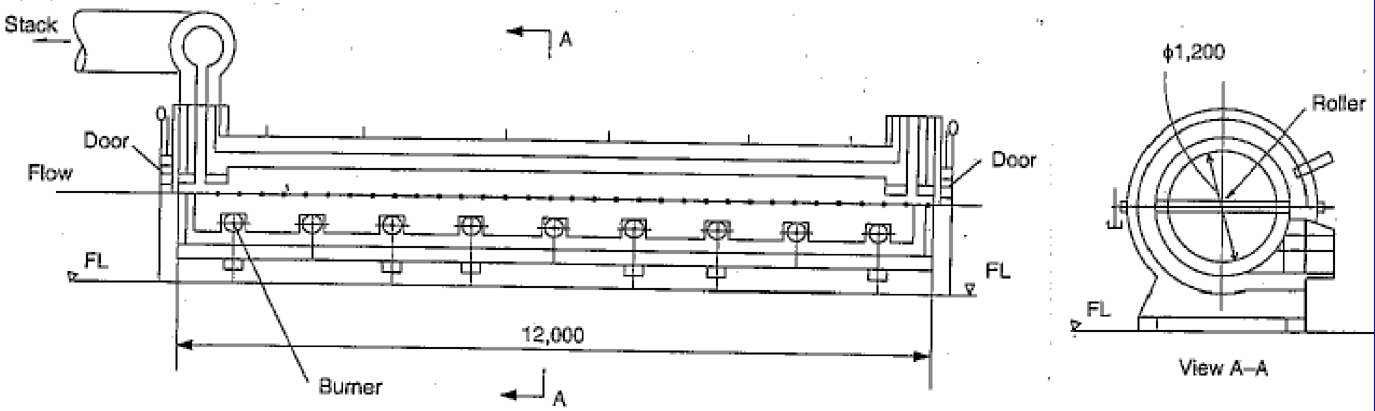


3) Capacity		1000 kg/h
4) Fuel	Heating Varyu of Heavy A Oil	42.11 MJ/kg
	Theoretical Air Requirement	11.09 m3N/kg
	Quantity of the Waste Gas (Air Ratio = 1)	11.82 m3N/kg
5) Fuel Consumption		61.315kg/h
6) Combustion Air Temp.		33℃
7) Fuel Temp.		33℃
8) Air Ratio		1.6
9) NOx in Exhaust Gas		250 ppm
10) Waste Gas Temp.		1000℃

Heating Furnace

1) Type Roller Hearth Type Bar Heating Furnace for Quenching

2) Dimension



11) Furnace Wall Temp.			1000℃
12) Material Temp.			33℃ → 950℃
13) Surface Temp. of Body	Cylindrical Wall		134℃
	Vertical Wall		135℃
14) Furnace Wall Structure	Fire Brick SK33		115 mm
	Insulating Brick B6		115 mm
15) Cooling Water Heat Loss			2m3/h 30℃ → 40℃
16) Furnace Pressure			49 Pa
17) Generated Scale			7 kg/ton of Raw Material
18) Average Specific Heat at Constant Pressure		Air	1.298 kJ/m3N℃
		Waste Gas	1.381 kJ/m3N℃
		Iron	0.699 kJ/kg℃
		Scale	0.900 kJ/kg℃
19) Heat of Oxidizing Reaction (Fe)			5.588 MJ/kg
20) Total Fe in Scale			0.755

Air ratio could be reduced to 1.2.

Scale loss at air ratio 1.2 would be 70% of that at air ratio 1.6.

21) Burner Type Compressed Air Atomizing Burner

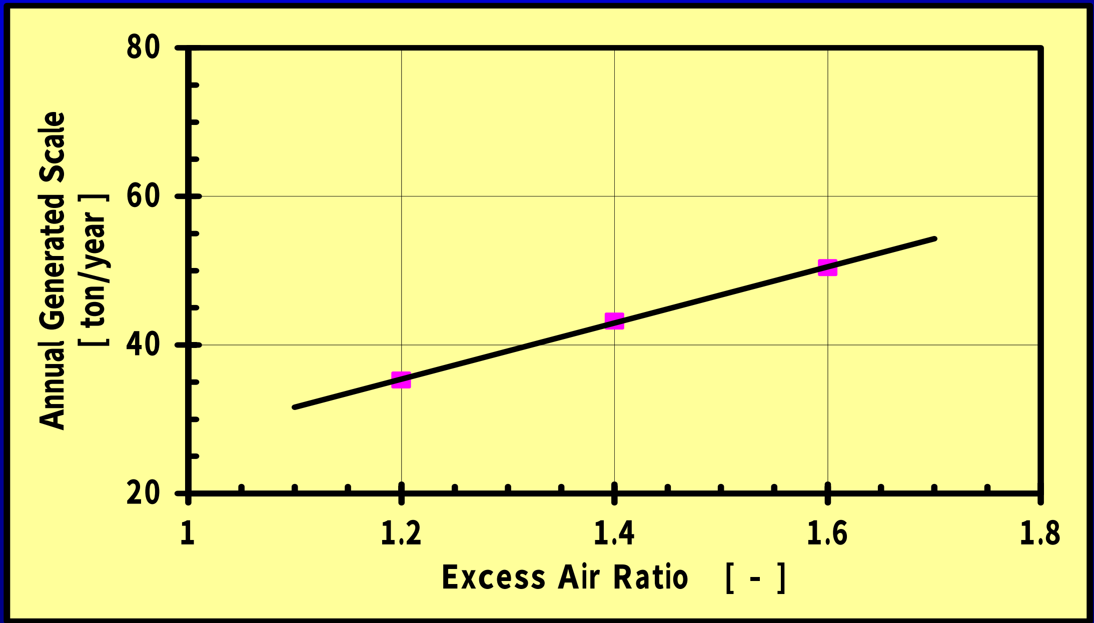
Veneering Thickness (mm)	0 (Existing)	25	50	75	100
Surface Tem. Cylindrical Wall (°C)	134	113	100	90	82
Surface Tem. Vertical Wall (°C)	135	118	106	97	91
Wall Heat Loss Cylindrical Wall (MJ/h)	356.9	262.8	206.2	168.5	141.5
Wall Heat Loss Vertical Wall (MJ/h)	14.4	11.3	9.3	7.9	6.9
Total Heat Loss (MJ/h)	371.3	274.1	215.5	176.4	148.4

Table 8. Wall Loss as Function of Veneering Thickness

Scale Loss Improvement

Excess Air Ratio	Generated Scale	Annual Generated Scale
-	kg/ton	ton/year
1.6	7.0	50.4
1.4	6.0	43.2
1.2	4.9	35.3

Heating Furnace Operation Hour : 7200 h/year



Heat Balance of the Current Furnace

Input Heat — Total 2612 MJ/h

1) Fuel's Heat Value — 2582.00 MJ/h

Fuel Consumption — Low Calorific Value
61.3154 kg/h * 42.11 MJ/kg

2) Scale's Producing Heat — 29.53 MJ/h

Generated Scale — Capacity
7 kg/ton * 0.755 * 1.0 ton/h * 5.588 MJ/kg
Total Fe in Scale — Heat of Oxidizing Reaction (Fe)

Output Heat — Total 2612 MJ/h

3) Material's Sensible Heat — 637.65 MJ/h

Capacity — Generated Scale — Material Temp.
(1000 kg/h - 0.755 * 7 kg/h) * 0.699 kJ/kg℃ * (950℃ -33℃)
Total Fe in Scale — Specific Heat of Iron

4) Exhaust Gas Loss — 1513.11 MJ/h

Specific Heat of Waste Gas — Fuel Consumption
1.381 kJ/m3N℃ * 18.474m3N/kg * 61.3154 kg/h * (1000℃ - 33℃)
Waste Gas Quantity — Waste Gas Temp.

Waste Gas Quantity — Theoretical Air Quantity
18.474 m3N/kg = 11.82 m3N/kg + 11.09 m3N/kg * (1.6 - 1.0)
Theoretical Waste Gas Quantity — Excess Air

5) Radiation Heat Loss from Furnace Wall — 371.34 MJ/h

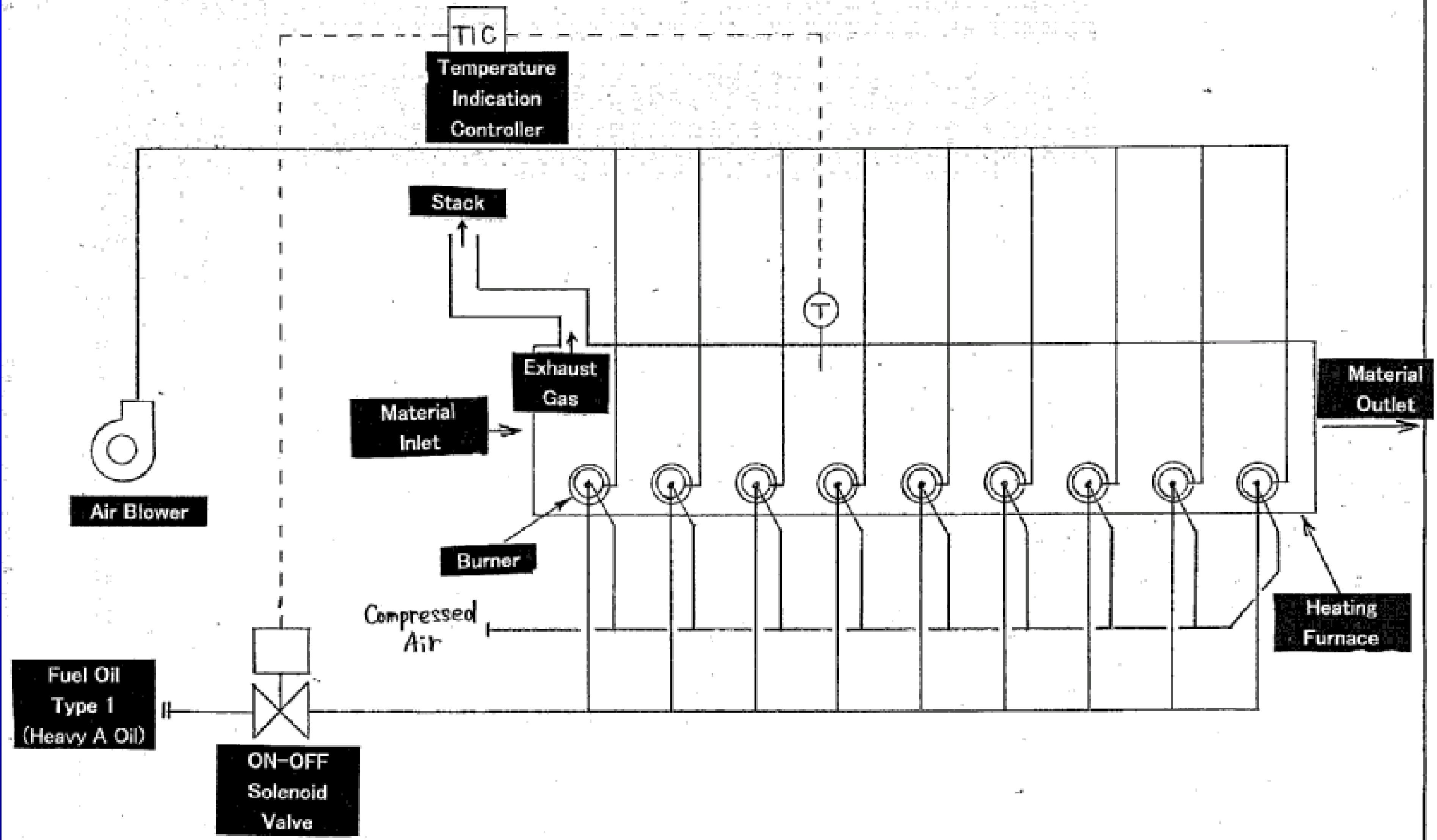
Heat Loss from Cylindrical Wall
356.90 MJ/h + 14.44 MJ/h
Heat Loss from Vertical Wall

6) Heat taken by Cooling Water — 83.72 MJ/h

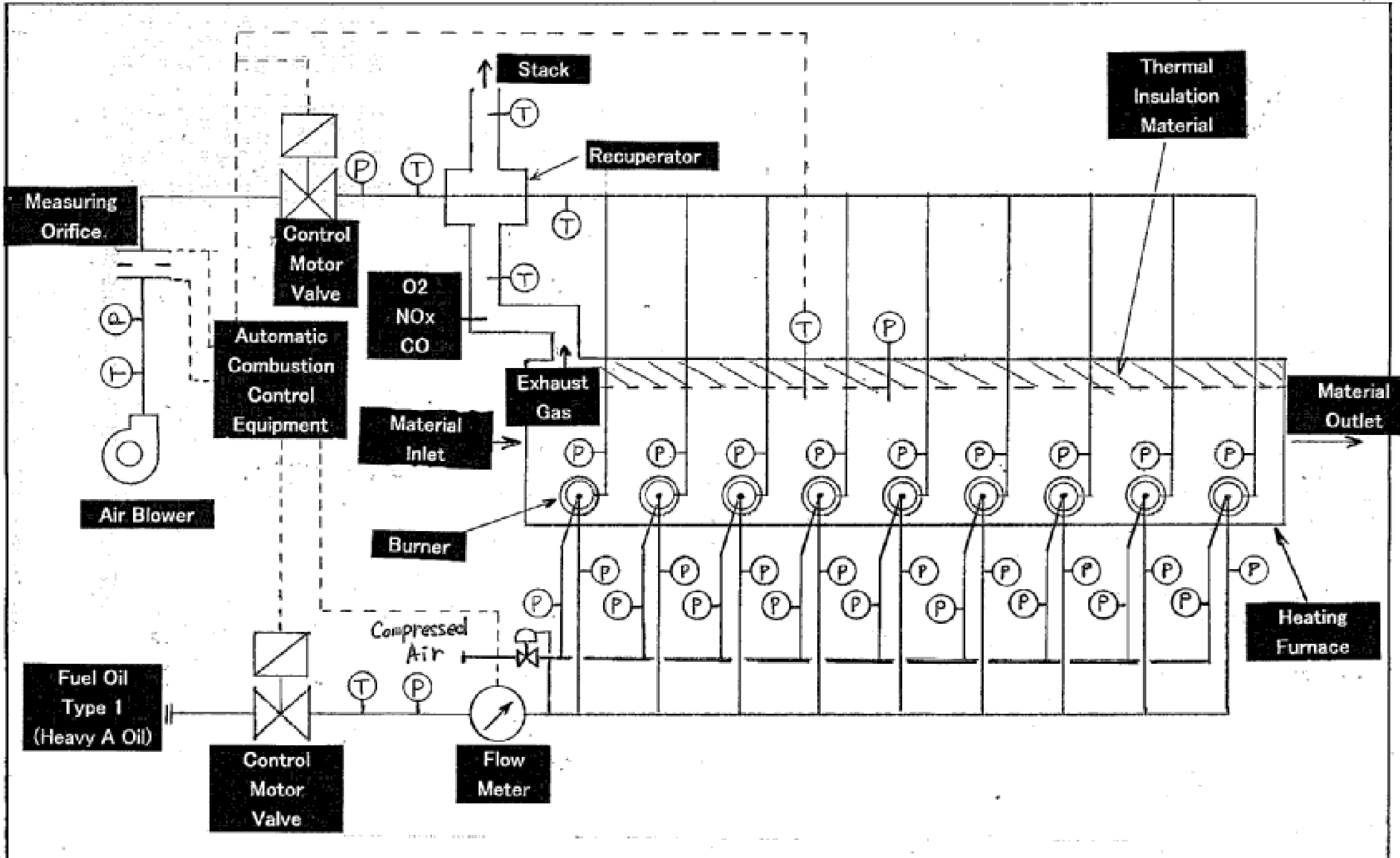
Specific Heat of Water — Cooling Water Quantity.
4.186 MJ/m3N℃ * (40 - 30) x 2 m3/h
Cooling Water Temp.

7) Scale's Sensible Heat — 5.78 MJ/h

Specific Heat of Scale — Material Temp.
0.900 kJ/kg℃ * 7 kg/h * (950℃ - 33℃)
Generated Scale



Current Flow Sheet



Improved Flow Sheet and Measurement Point

Calculation of Heat Balance Improvement

Input Heat — Total (X * 51.90 + 20.67) MJ/h

1) Fuel's Heat Value — X * 42.11 MJ/h

Fuel Consumption × Low Calorific Value
X kg/h * 42.11 MJ/kg

2) Preheated Air's Sensible Heat — X * 9.79 MJ/h

Theoretical Air Quantity × Air Ratio × Specific Heat of Air × Fuel Consumption × (Preheat Air Temp.)
11.09 m3N/kg * 1.2 * 1.298 kJ/m3N℃ * X kg/h * (600℃ - 33℃)

3) Scale's Producing Heat — 20.67 MJ/h

Generated Scale × Scale Loss Improvement × Total Fe in Scale × Capacity × Heat of Oxidizing Reaction (Fe)
7 kg/ton * 0.7 * 0.755 * 1.0 ton/h * 5.588 MJ/kg

Output Heat — Total (X * 18.75 + 941.96) MJ/h

4) Material's Sensible Heat — 638.67 MJ/h

Capacity − Total Fe in Scale × Generated Scale × Scale Loss Improvement × Specific Heat of Iron × (Material Temp.)
(1000 kg/h - 0.755 * 7 kg/h * 0.7) * 0.699 kJ/kg℃ * (950℃ -33℃)

5) Exhaust Gas Loss — X * 18.75 MJ/h

Specific Heat of Waste Gas × Waste Gas Quantity × Fuel Consumption × (Exhaust Gas Temp.)
1.381 kJ/m3N℃ * 14.038m3N/kg * X kg/h * (1000℃ - 33℃)

Waste Gas Quantity = Theoretical Waste Gas Quantity + Theoretical Air Quantity × (Excess Air)
14.038 m3N/kg = 11.82 m3N/kg + 11.09 m3N/kg * (1.2 - 1.0)

6) Radiation Heat Loss from Furnace Wall (50mm Veneering) — 215.53 MJ/h

Heat Loss from Cylindrical Wall + Heat Loss from Vertical Wall
206.24 MJ/h + 9.29 MJ/h

7) Heat taken by Cooling Water — 83.72 MJ/h

Specific Heat of Water × (Cooling Water Temp.) × Cooling Water Quantity.
4.186 MJ/m3N℃ * (40℃ - 30℃) * 2 m3/h

8) Scale's Sensible Heat — 4.04 MJ/h

Specific Heat of Scale × Generated Scale × Scale Loss Improvement × (Material Temp.)
0.900 kJ/kg℃ * 7 kg/h * 0.7 * (950℃ - 33℃)

Price List of Improved Equipment and Other Related Items for Heating Furnace

Improved Equipment Name	Specifications	Price US$ (Including Laborage)
1. Automatic Combustion Control Equipment (Including Damper Control)	Temperature Control Flow Rate Control Automatic Valve	32000
2. Thermal Insulation Material	Ceramic Fiber 25mm Plywood Ring 50mm 75mm 100mm	16600 23800 33300 40400
3. Waste Heat Recovery Collecting System 1 (Large Size)	Recuperator Max. Exhaust Gas Volume 1100 m3N/h Max. Air Volume 1000 m3N/h Exhaust Gas Intake Temp. 800℃ Air Outlet Temp. 650℃ Air Duct Thermal Insulation	120000
4. Waste Heat Recovery Collecting System 2 (Small Size)	Recuperator Max. Exhaust Gas Volume 500 m3N/h Max. Air Volume 450 m3N/h Exhaust Gas Intake Temp. 800℃ Air Outlet Temp. 650℃ Air Duct Thermal Insulation	50000

Heat Balance and Payback 1

(Low Fuel Charge 0.1 $/kg)

Operation=7200 h/year   Interest=10%/year

Case Number			Original A	First Step Air Ratio B	Second Step Veneering C	Third Step Recuperator D	Ideal Improvement E
Input Data	Air Ratio	-	1.6	1.2	1.2	1.2	1.2
Input Data	Scale Loss Improvement	-	1	0.7	0.7	0.7	0.7
Input Data	Insulation Thickness	mm	0	0	50	50	50
Input Data	Wall Loss (Table 8 in Text)	MJ/h	371	371	216	216	216
Input Data	Preheated Air Temp	℃	33	33	33	600	600
Fuel Consumption		kg/h	61.3	46.1	39.4	27.8	27.8
Annual Fuel Consumption		kg/year	441306	331919	283904	200043	200043
Annual Fuel Cost		US $/year	44131	33192	28390	20004	20004
Annual Fuel Cost Saving		**US $/year**	**0**	**10939**	**4801**	**8386**	**24126**
Input	Fuel's Heat Value	MJ/h	2581	1941	1660	1170	1170
Input	Preheated Air's Sensible Heat	MJ/h	0	0	0	272	272
Input	Scale Producing Heat	MJ/h	30	21	21	21	21
Output	Material's Sensible Heat	MJ/h	638	639	639	639	639
Output	Exhaust Gas Loss	MJ/h	1512	864	739	521	521
Output	Wall Loss	MJ/h	371	371	216	216	216
Output	Cooling Water Loss	MJ/h	84	84	84	84	84
Output	Scale's Sensible Heat	MJ/h	6	4	4	4	4
Total Input		MJ/h	2611	1962	1681	1463	1463
Total Output		MJ/h	2611	1962	1681	1463	1463
Input - Output		MJ/h	0	0	0	0	0
Investment of Air Control (Price List in Text)		US $	0	32000	0	0	32000
Investment of Insulation (Price List in Text)		US $	0	0	23800	0	23800
Investment of Air Preheat (Price List in Text)		US $	0	0	0	50000	50000
Total Investment		**US $**	**0**	**32000**	**23800**	**50000**	**105800**
Payback year	**(Interest 10%)**	**year**	**0.0**	**3.6**	**7.2**	**9.5**	**6.1**
	(Interest 5%)		**0.0**	**3.2**	**5.8**	**7.3**	**5.1**
	(Interest 3%)		**0.0**	**3.1**	**5.4**	**6.7**	**4.8**

Goal Seek

Heat Balance and Payback 2

(High Fuel Charge 0.2 $/kg)

Operation=7200 h/year Interest=10%/year

Case Number			Original A	First Step Air Ratio B	Second Step Veneering C	Third Step Recuperator D	Ideal Improvement E
Input Data	Air Ratio	-	1.6	1.2	1.2	1.2	1.2
Input Data	Scale Loss Improvement	-	1	0.7	0.7	0.7	0.7
Input Data	Insulation Thickness	mm	0	0	50	50	50
Input Data	Wall Loss (Table 8 in Text)	MJ/h	371	371	216	216	216
Input Data	Preheated Air Temp	°C	33	33	33	600	600
Fuel Consumption		kg/h	61.3	46.1	39.4	27.8	27.8
Annual Fuel Consumption		kg/year	441306	331919	283904	200043	200043
Annual Fuel Cost		US $/year	88261	66384	56781	40009	40009
Annual Fuel Cost Saving		**US $/year**	**0**	**21877**	**9603**	**16772**	**48253**
Input	Fuel's Heat Value	MJ/h	2581	1941	1660	1170	1170
Input	Preheated Air's Sensible Heat	MJ/h	0	0	0	272	272
Input	Scale Producing Heat	MJ/h	30	21	21	21	21
Output	Material's Sensible Heat	MJ/h	638	639	639	639	639
Output	Exhaust Gas Loss	MJ/h	1512	864	739	521	521
Output	Wall Loss	MJ/h	371	371	216	216	216
Output	Cooling Water Loss	MJ/h	84	84	84	84	84
Output	Scale's Sensible Heat	MJ/h	6	4	4	4	4
Total Input		MJ/h	2611	1962	1681	1463	1463
Total Output		MJ/h	2611	1962	1681	1463	1463
Input - Output		MJ/h	0	0	0	0	0
Investment of Air Control (Price List in Text)		US $	0	32000	0	0	32000
Investment of Insulation (Price List in Text)		US $	0	0	23800	0	23800
Investment of Air Preheat (Price List in Text)		US $	0	0	0	50000	50000
Total Investment		**US $**	**0**	**32000**	**23800**	**50000**	**105800**
Payback year	**(Interest 10%)**	**year**	**0.0**	**1.7**	**3.0**	**3.7**	**2.6**
	(Interest 5%)		**0.0**	**1.6**	**2.7**	**3.3**	**2.4**
	(Interest 3%)		**0.0**	**1.5**	**2.6**	**3.2**	**2.3**

Goal Seek (Input - Output → Fuel Consumption)