Text No.24

COMBUSTION TECHNOLOGIES FOR ENERGY CONSERVATION

省エネルギーのための燃焼技術

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Isamu Ikeda

General Manager
Thermo System Company, Technology Department
Chugairo Co., Ltd.

池田　勇

中外炉工業株式会社
サーモシステム・カンパニー技術部部長

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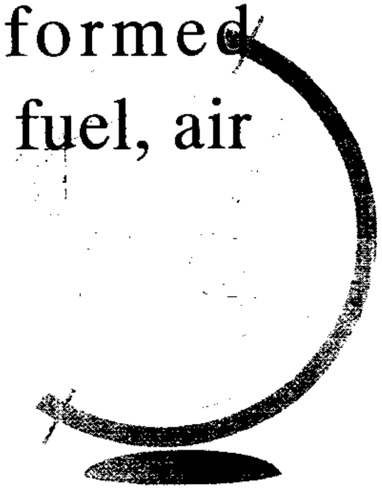
- How to Save Energy

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.

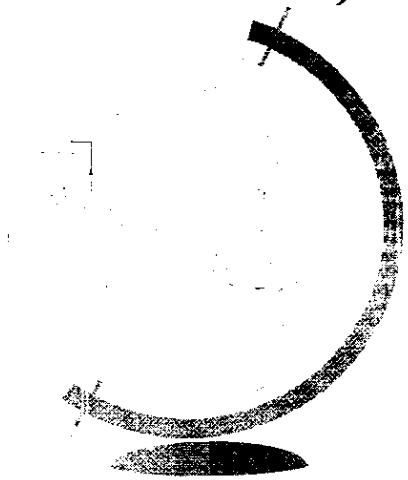
- Flame is the state of gas phase and formed generally in the flow region of mixture of fuel, air and burning products.



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



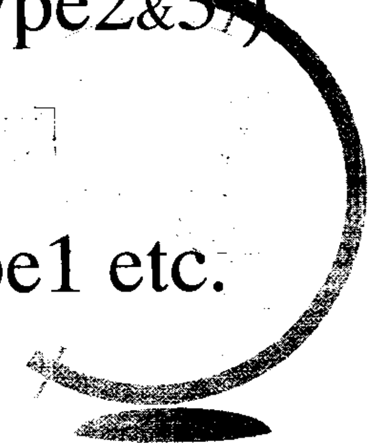
Name	Component %									Density	Low Calorific Value	Theoretical Air Requirement	Theoretical Combustion Product m^3N/m^3N		
	CO_2	CO	CH_4	C_3H_8	C_4H_{10}	CmHn	H_2	O_2	N_2	kg/m^3N	MJ/m^3N	m^3N/m^3N	CO_2	H_2O	N_2
Butane Gas	0	0	0	0	100	0	0	0	0	2.593	118.6	31.09	4.00	5.00	24.59
Propane Gas	0	0	0	100	0	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 (10000 kcal/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

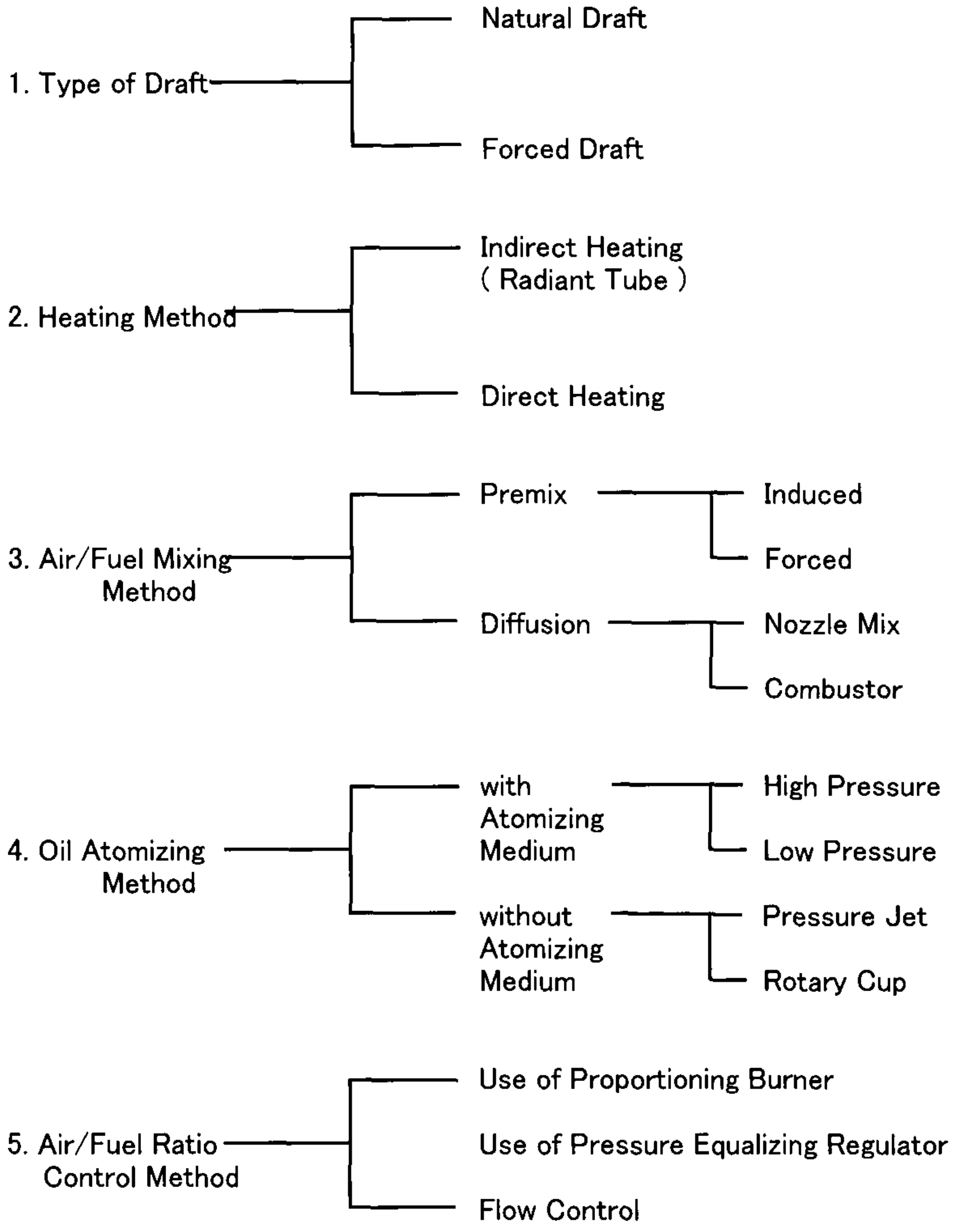
Name	Component wt %							True Specific Gravity	Low Calorific Value	Theoretical Air Requirement	Theoretical Combustion Product m^3N/kg			
	C	H	O	N	S	H_2O	Ash	g/cm^3	MJ/kg	m^3N/kg	CO_2	H_2O	SO_2	N_2
Foundry Coke	85.5	0.3	0.1	0	0.5	0.3	12.6	1.8〜2.0	28.9	7.75	1.61	0.03	0.00	6.09
Iron-making Coke	79.4	0.4	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

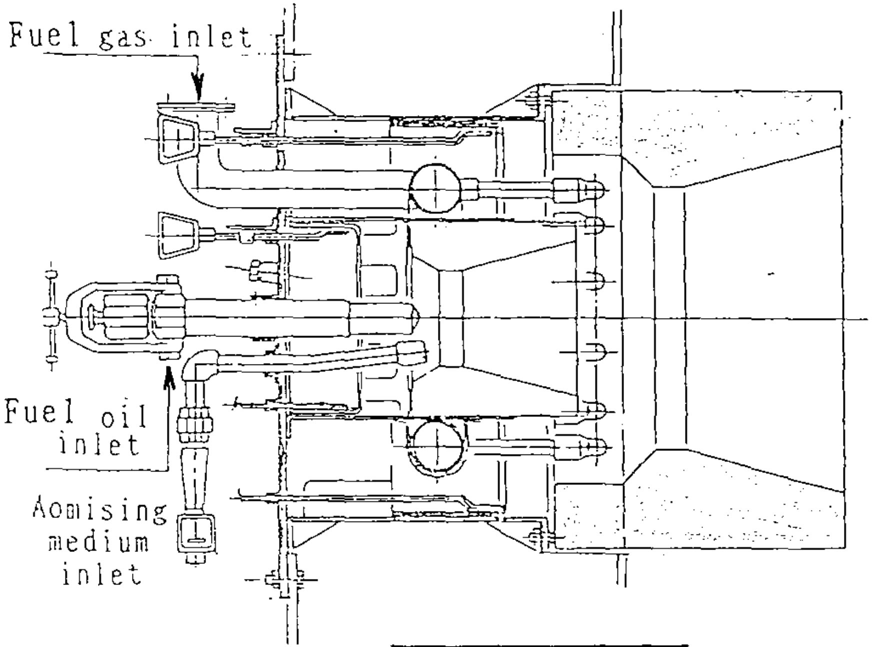
Classification of Burner

- 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



Classification by Type of Draft



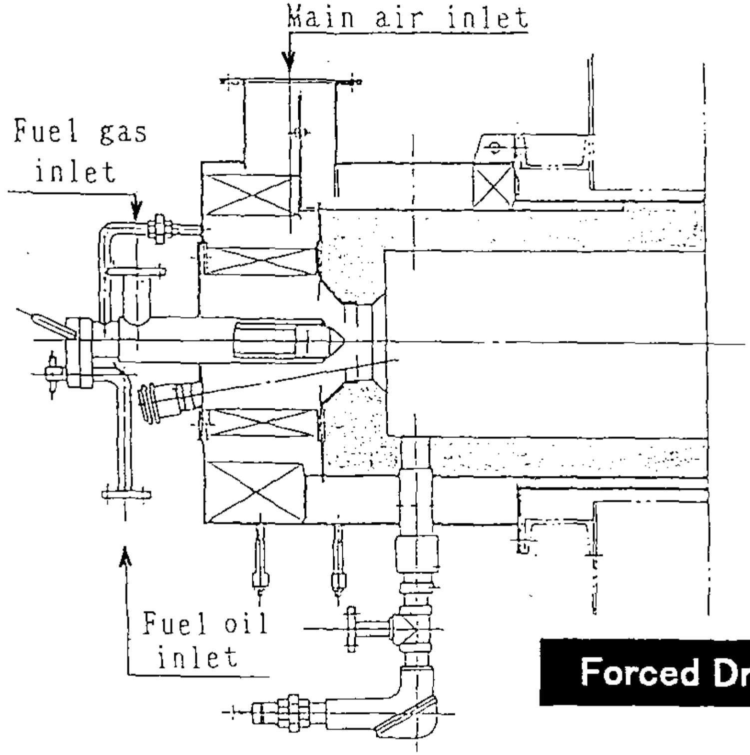
Natural Draft

Oil/gas combination burner (Model:PCMG)

Air/fuel ratio : 1.3～1.5

Prehdated air : not used

Turndown : 1:4



Forced Draft

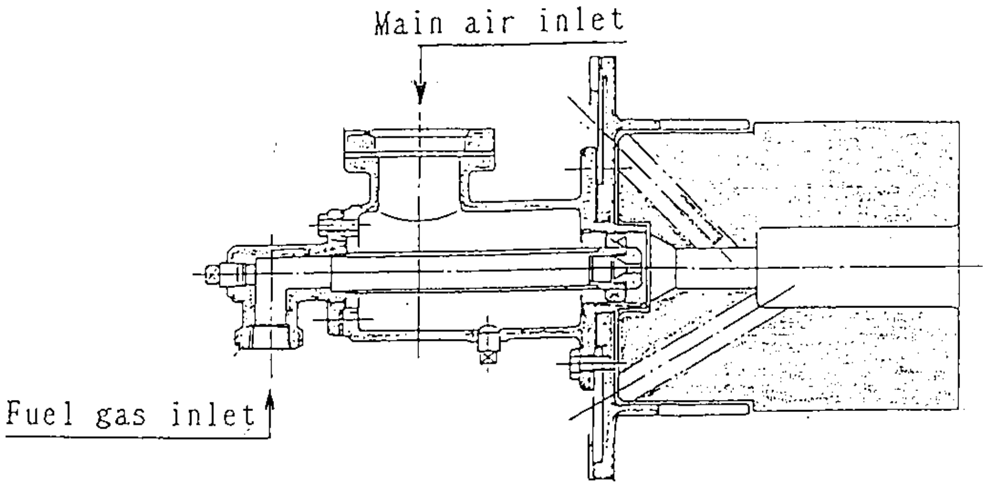
Vortometric oil/gas combination burner (Model:CVS)

Air/fuel ratio : 1.05～1.1

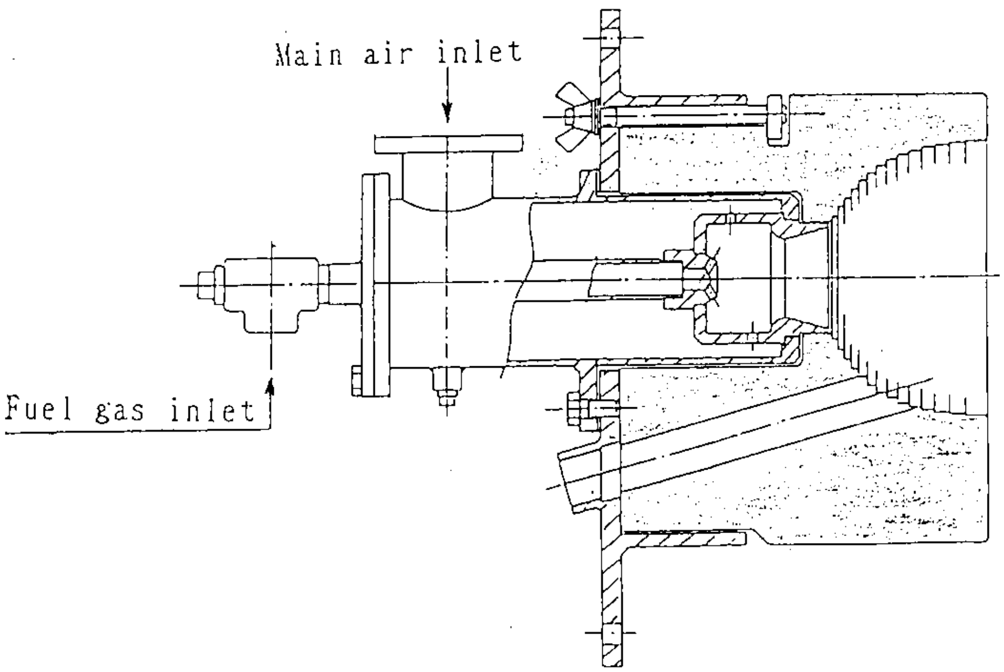
Preheated air : to be used

Turndown : 1:10

Classification by Heating Method Direct

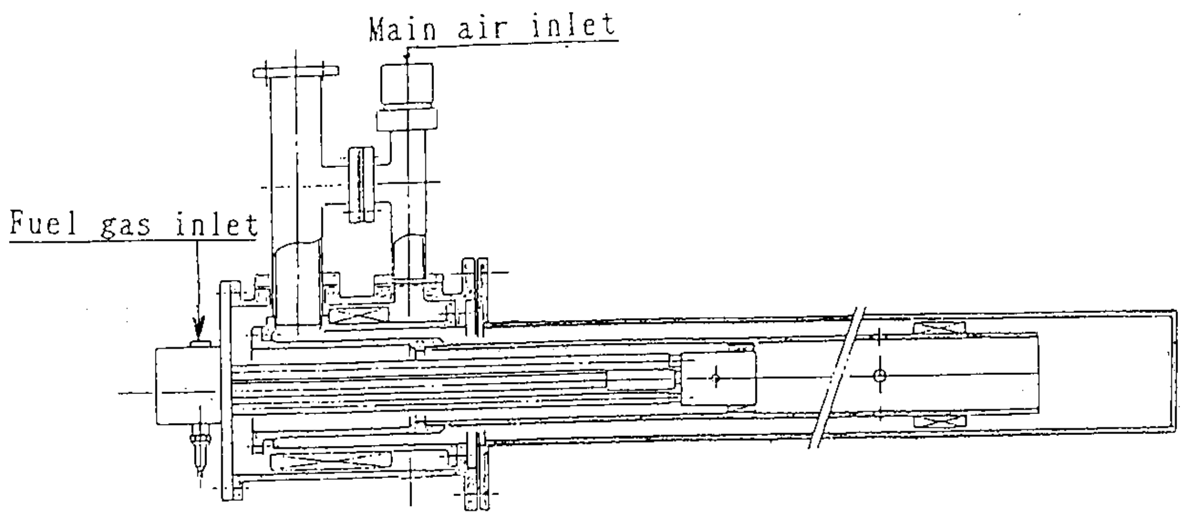


Convection heating
High momentum gas burner (Model:HMG)



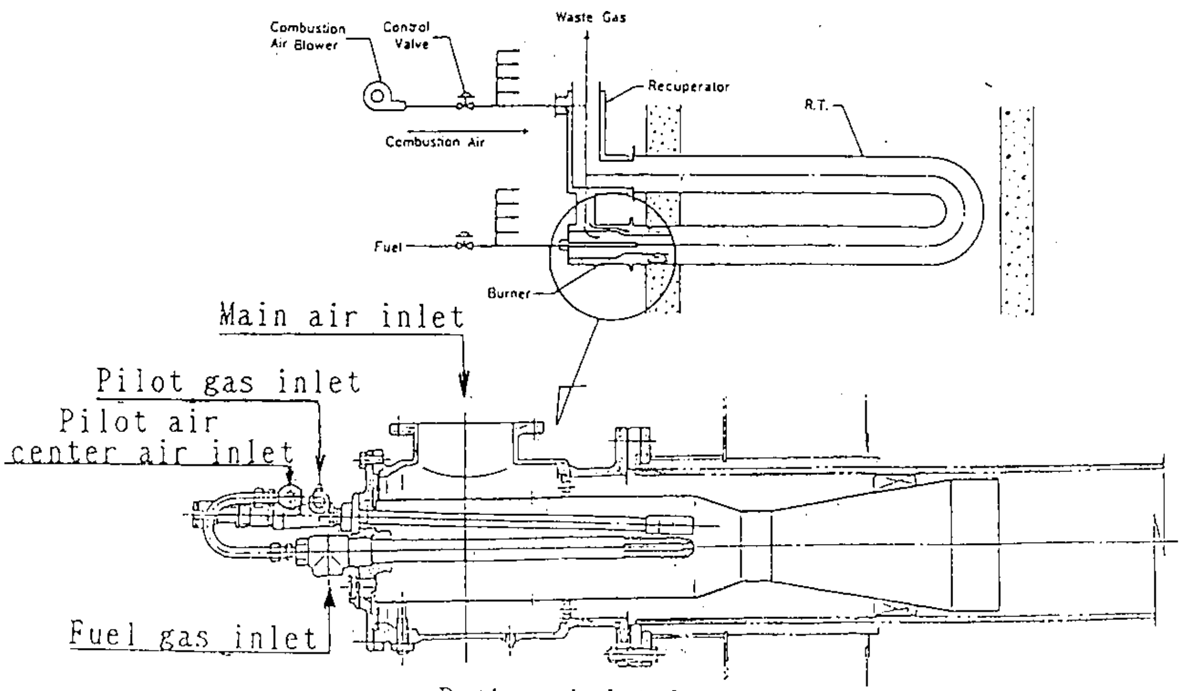
Radiative heating
Flat flame gas buener (Model:HFB)

Classification by Heating Method Indirect



Single ended tube

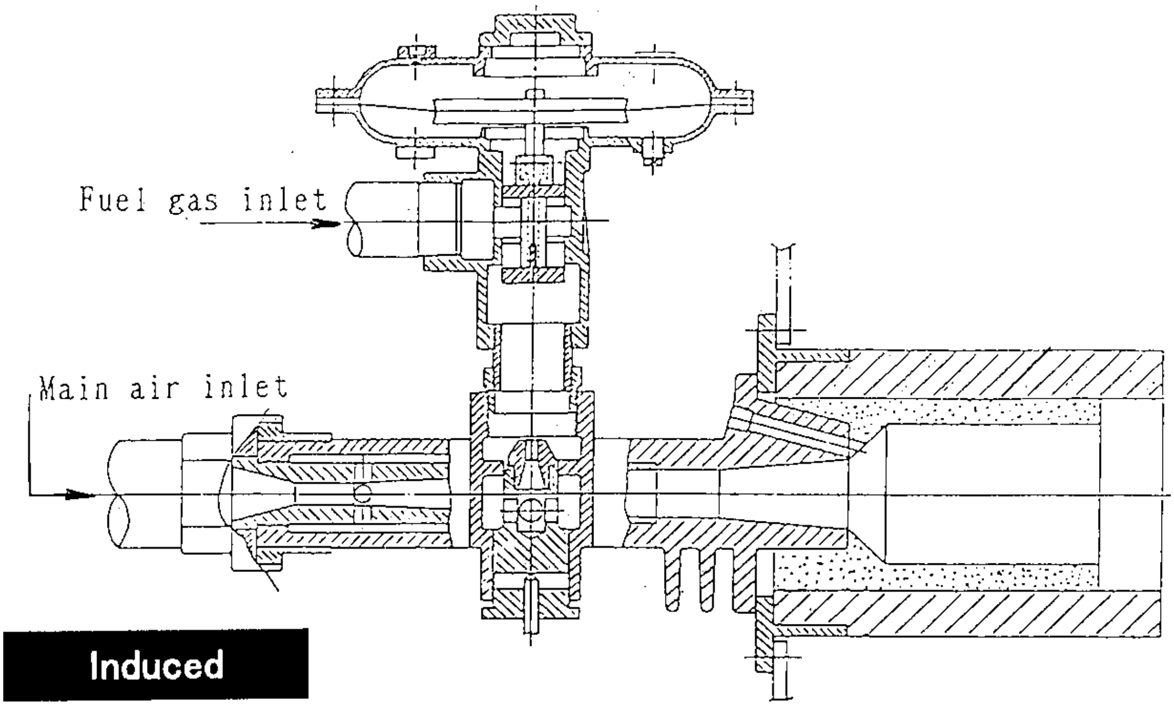
Concentric radiant tube unit (Model:CRB)



Both ended tube

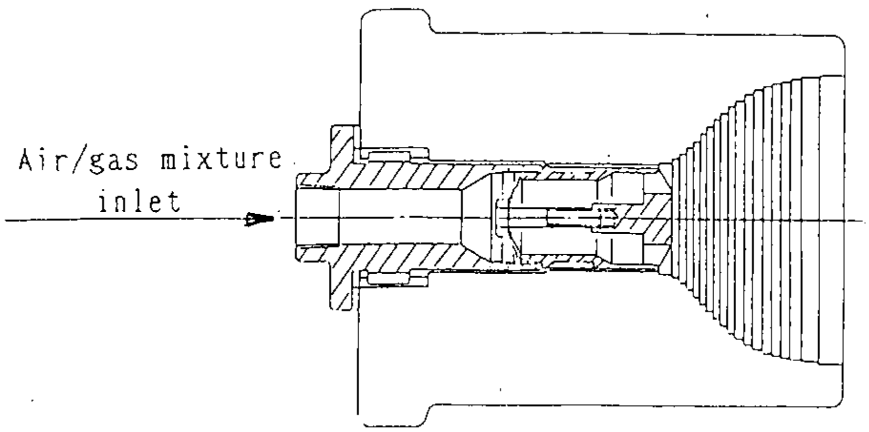
Low NOx rediant tube burner (Model:RBG-NR)

Classification by Air/Fuel Mixing Method Premix



Induced

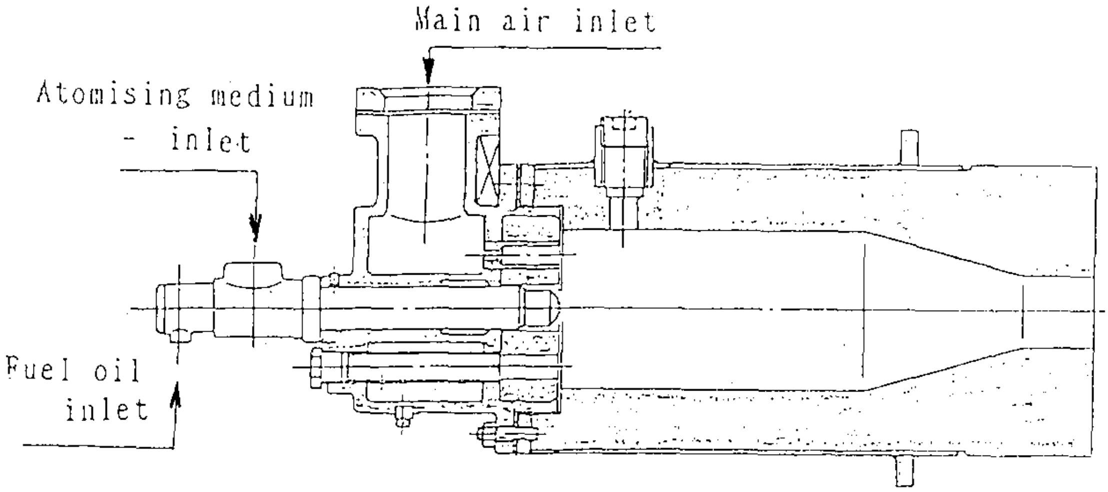
Low pressure velocity burner (Model:LP)



Forced

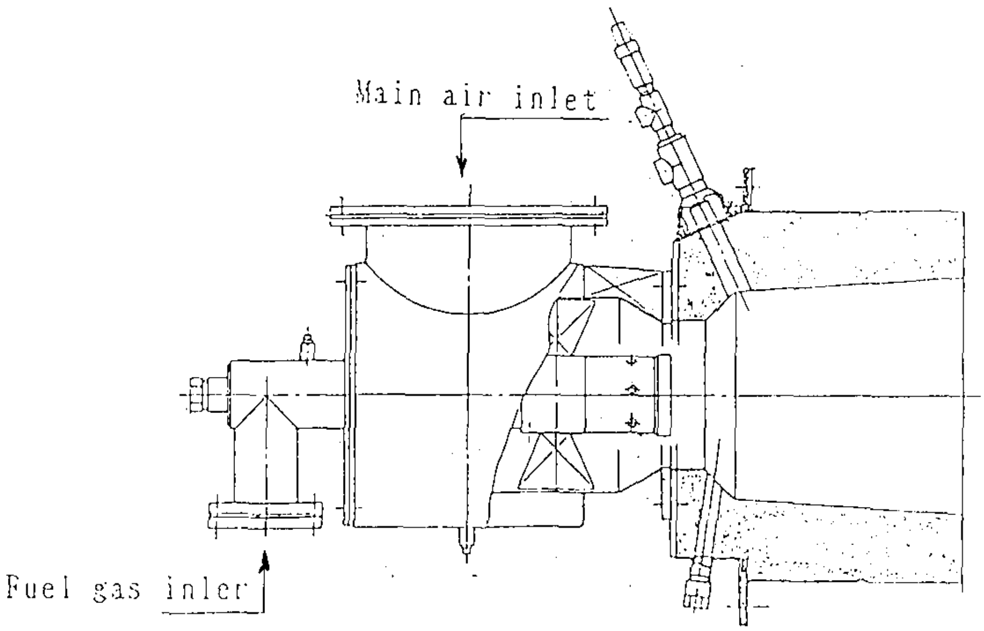
Radiation gas burner (Model:EFB)

Classification by Air/Fuel Mixing Method Diffusion



Combustor

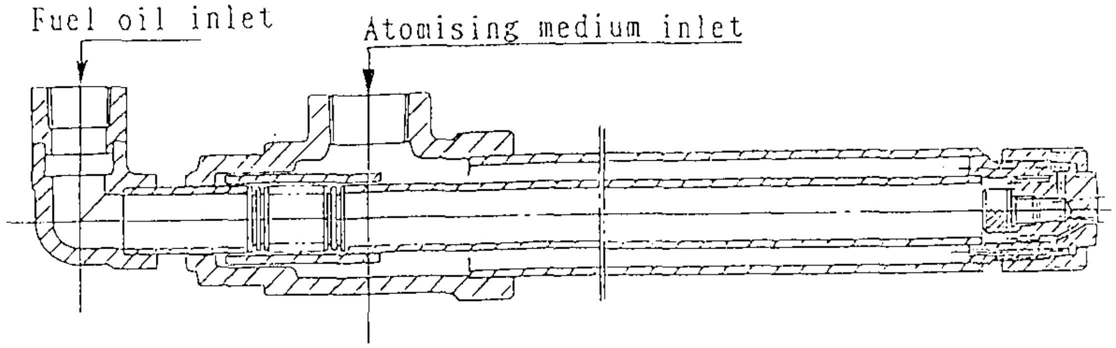
High speed excess air buener (Model:HC)



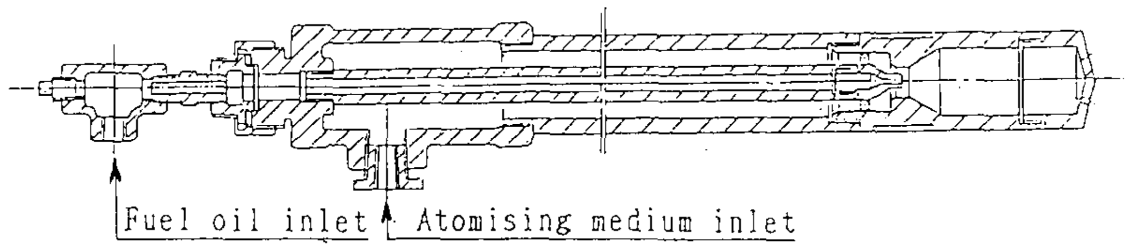
Nozzle Mix

Nozzle mix gas burner (Model:NG)

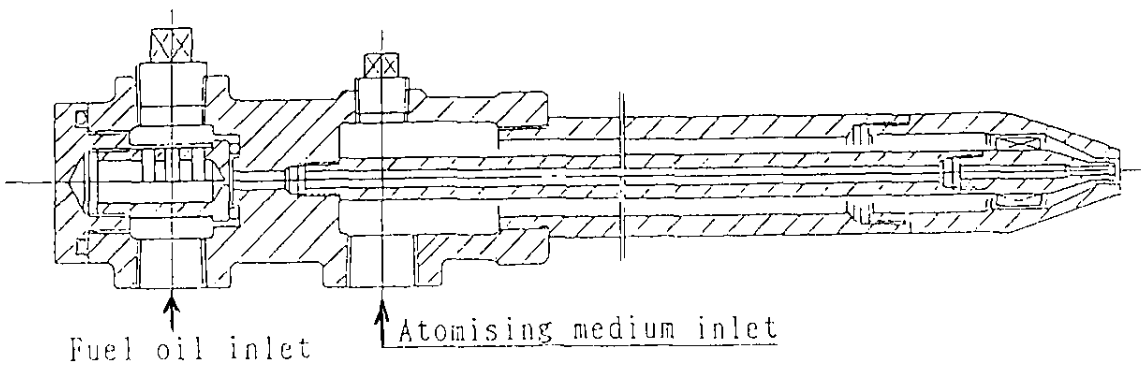
Classification by atomizing Method　Compressed Medium



Y-jet atomiser (Model:SEA)

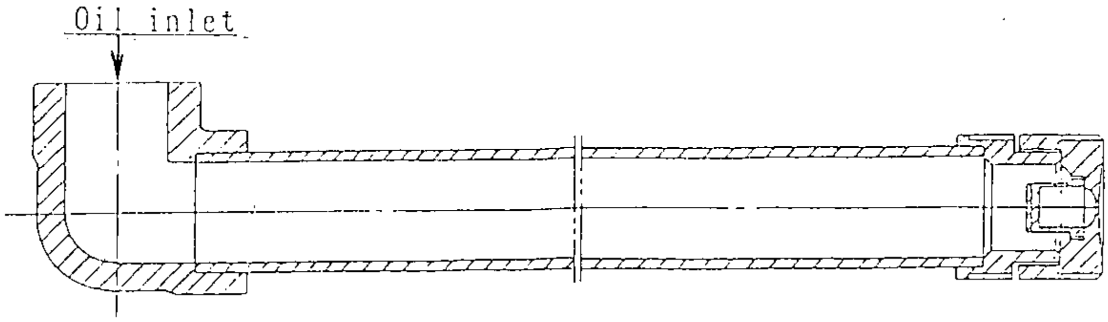


Internal mix atomiser (Model:MB)

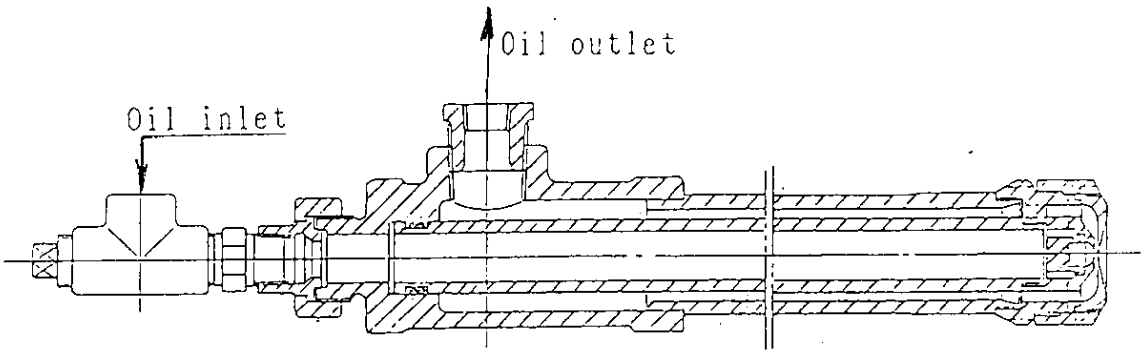


External mix atomiser (Model:HB)

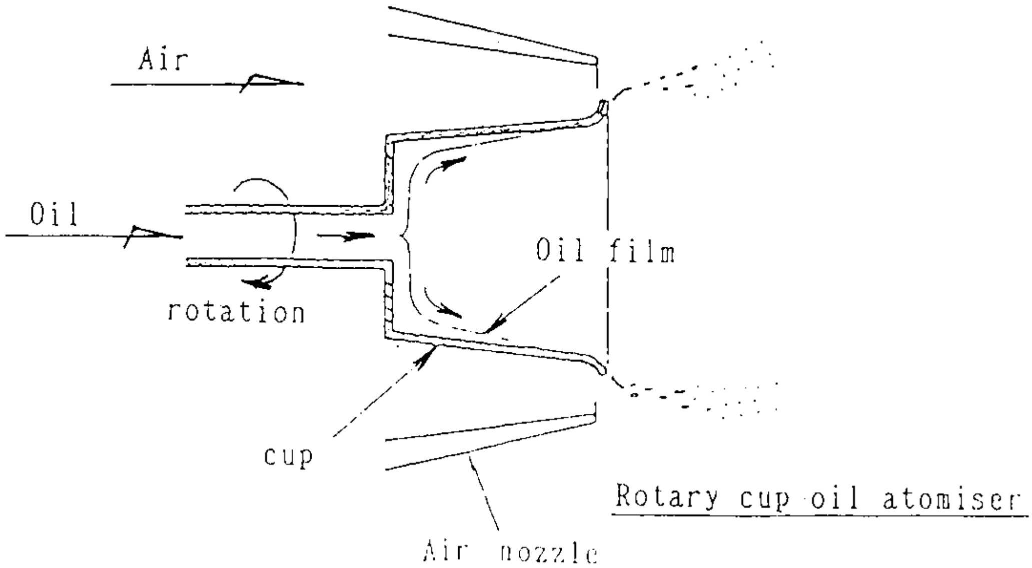
Classification by atomizing Method No Atomizing Medium



Pressure jet atomiser-No oil return

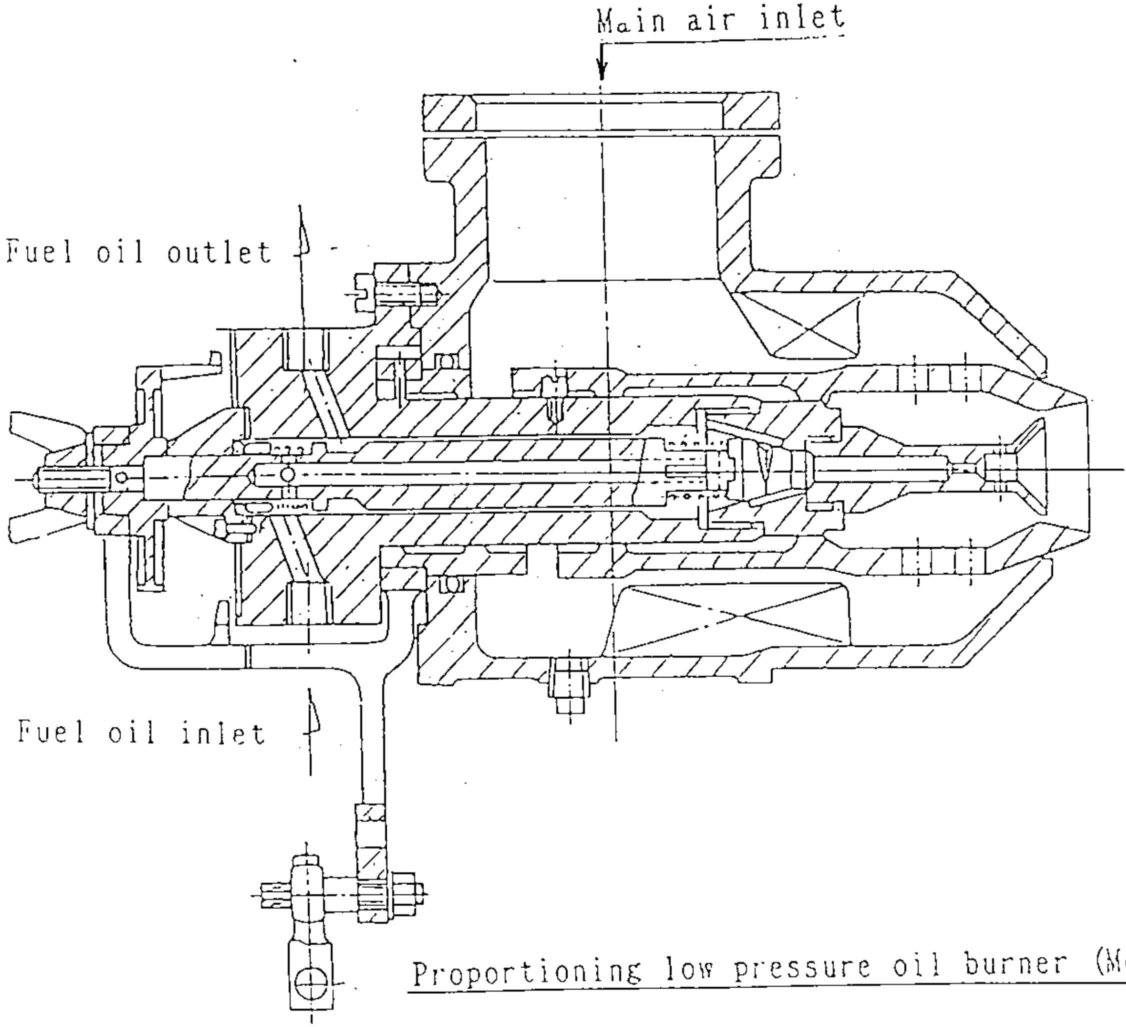


Pressure jet atomiser-oil return

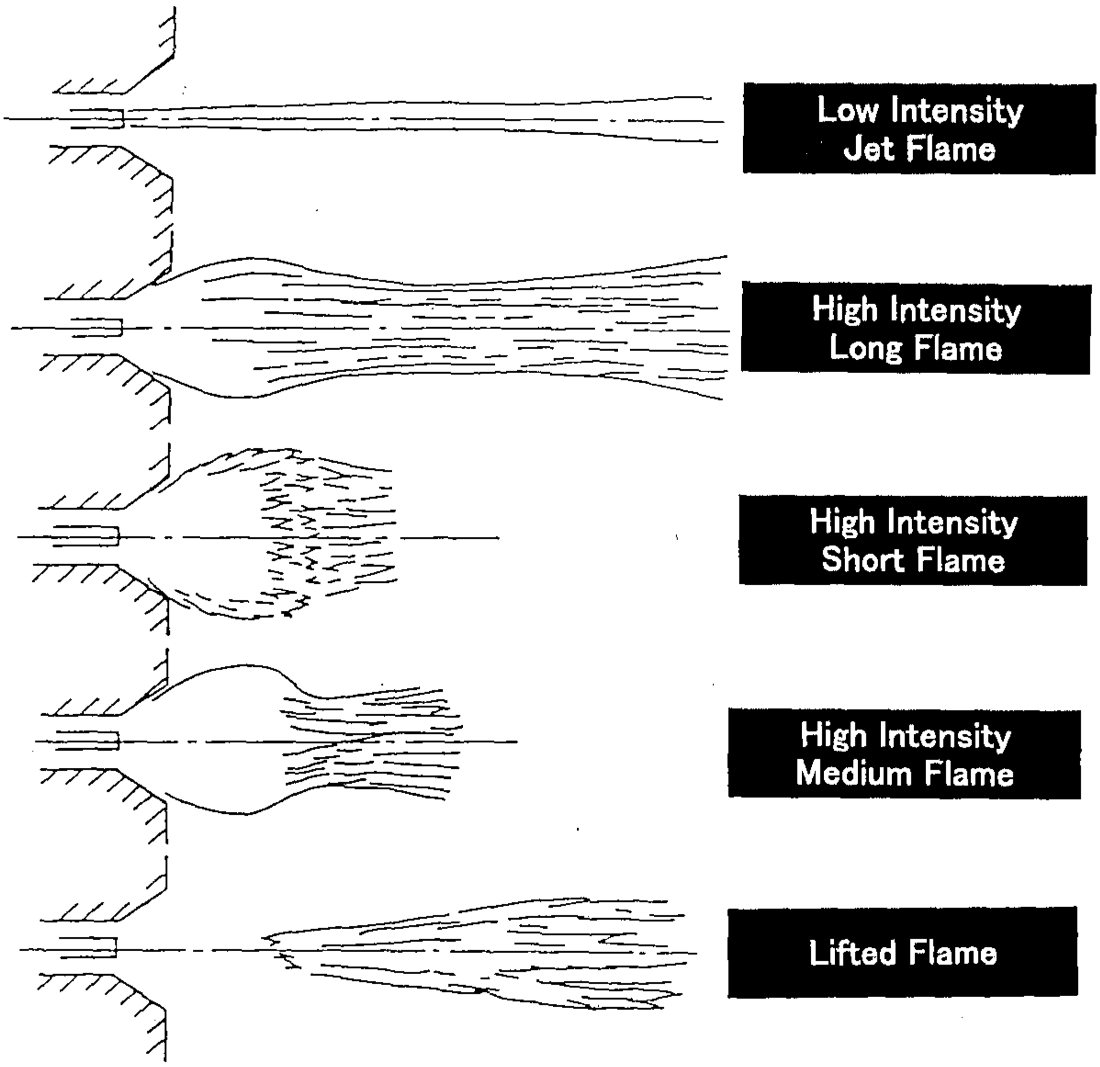


Rotary cup oil atomiser

Classification by atomizing Method　Low Pressure Air



Proportioning low pressure oil burner (Model:PLB)



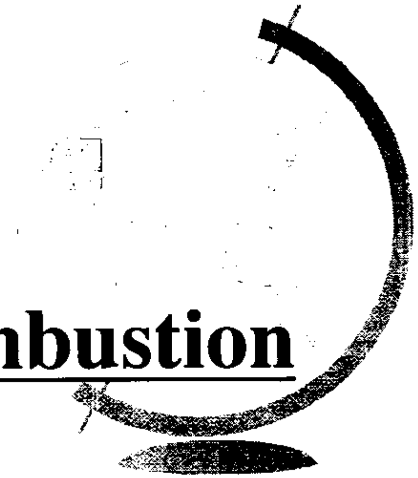
Simple Flame Classification Scheme

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

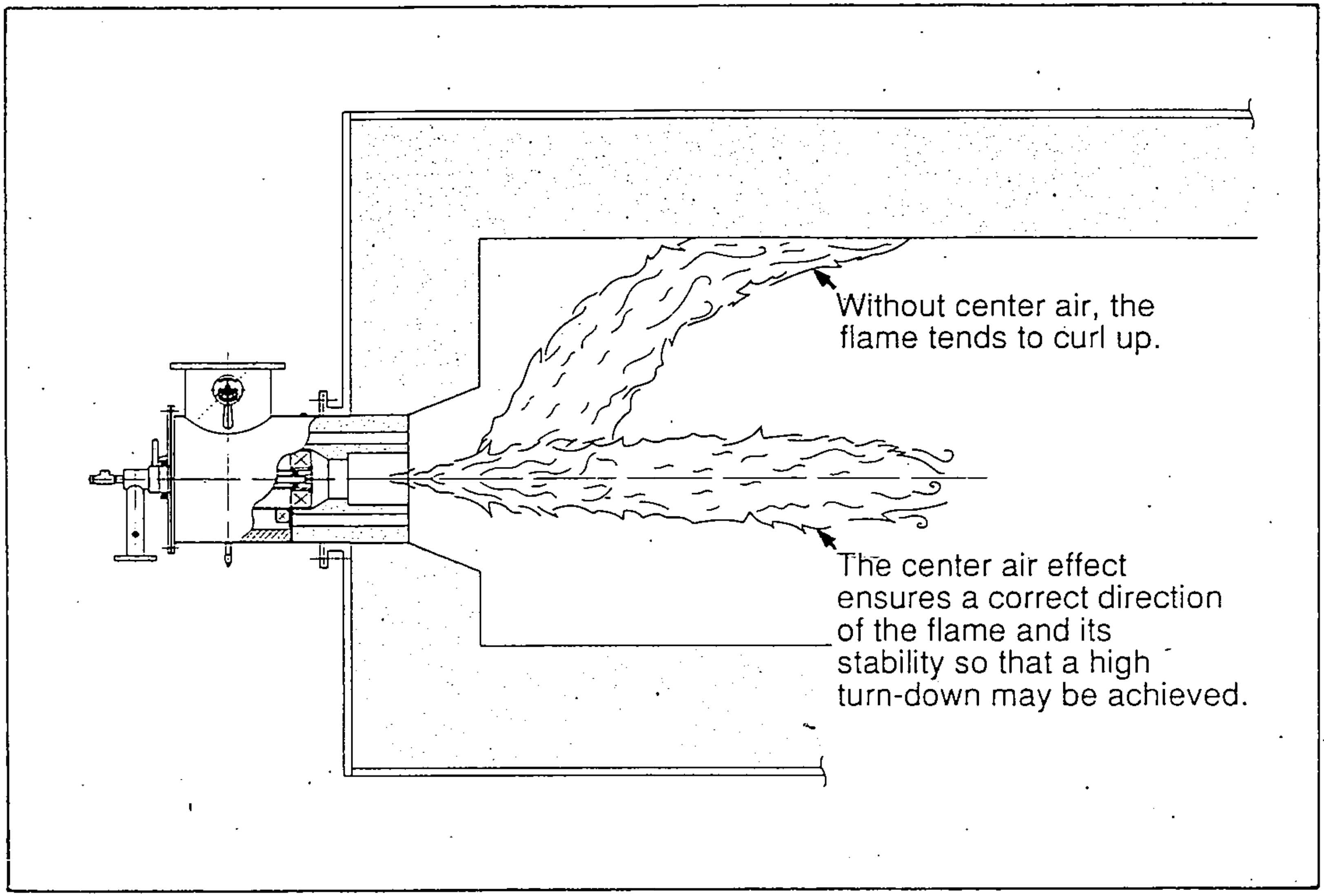
- Oxygen Deficient Combustion
- Coal Slurry
- Oil Residue
- Waste Products
- Blacking Technique
- Intelligent Burner System
- **Regenerative Burner**
- **Computational Simulation of Combustion**



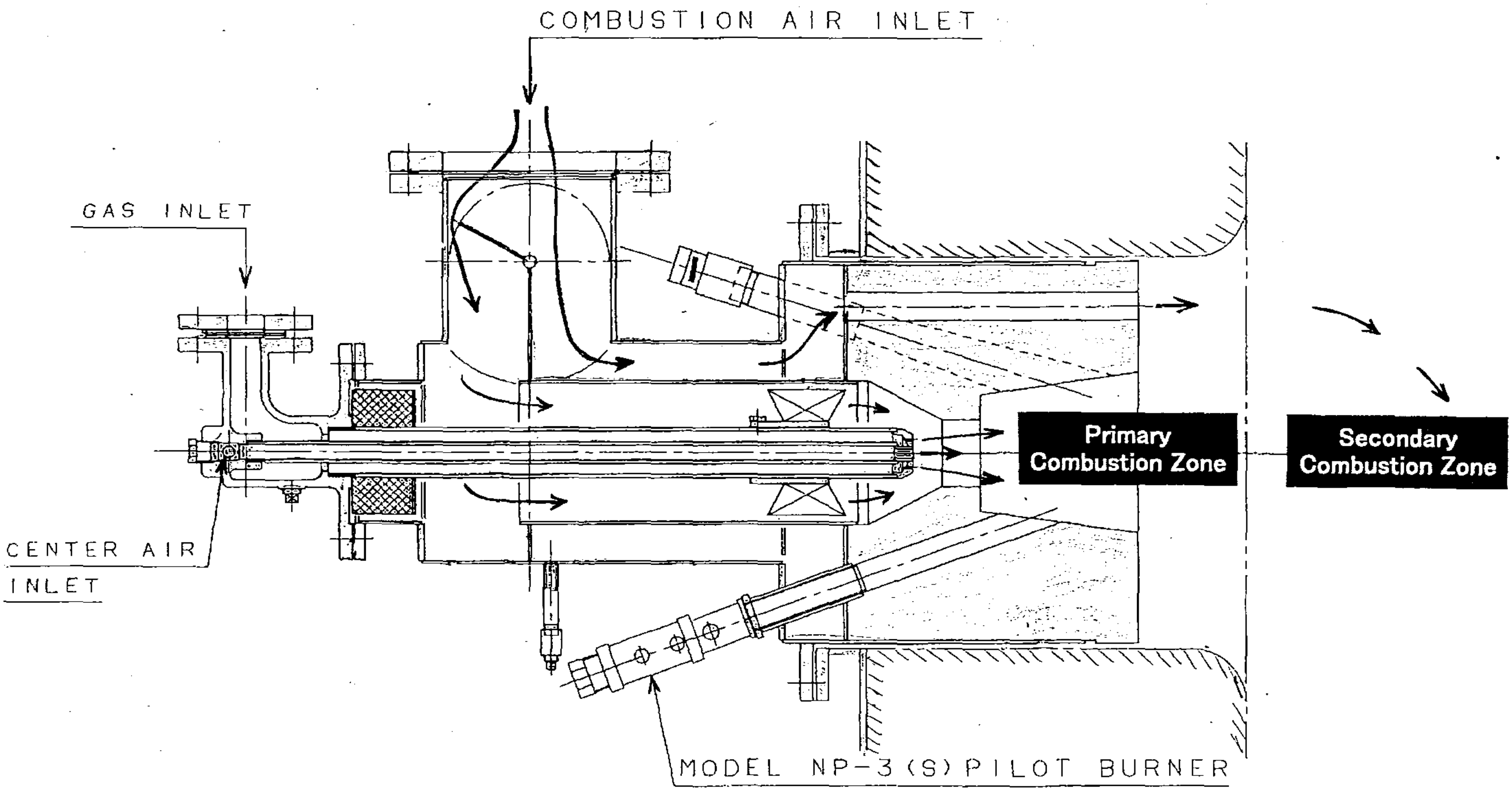
New Combustion Technology (1)

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

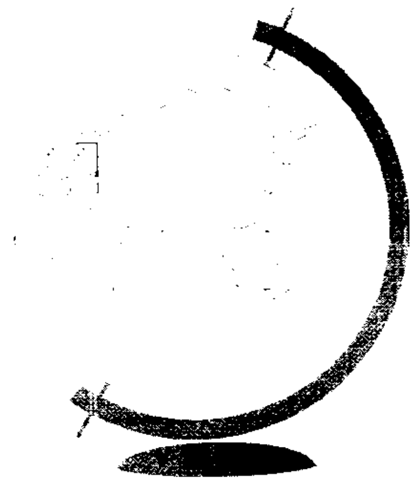


Type FHC High Turn Down Low NOx Burner

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 NOx Emission

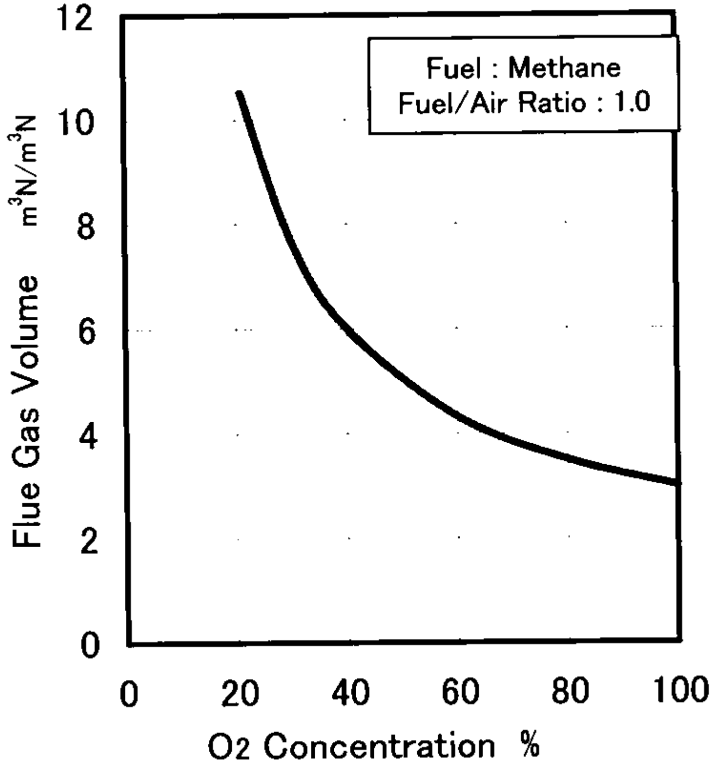


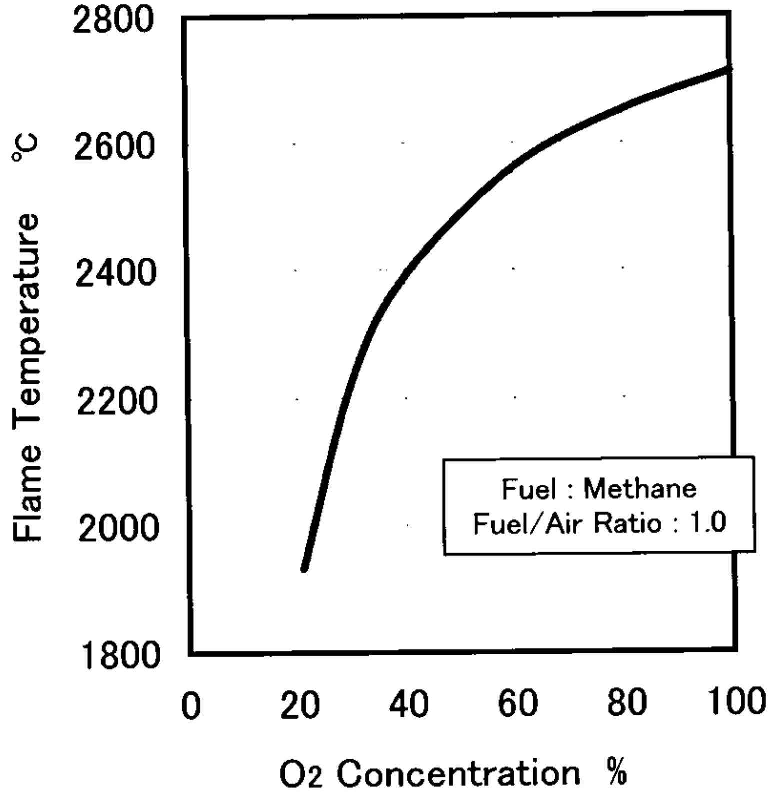
Composition	N_2	O_2	Ar	CO_2	Ne	He	Total
Volume %	78.09	20.95	0.930	0.030	0.002	0.001	100.00
Weight %	75.52	23.15	1.280	0.046	0.001	0.000	100.00

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

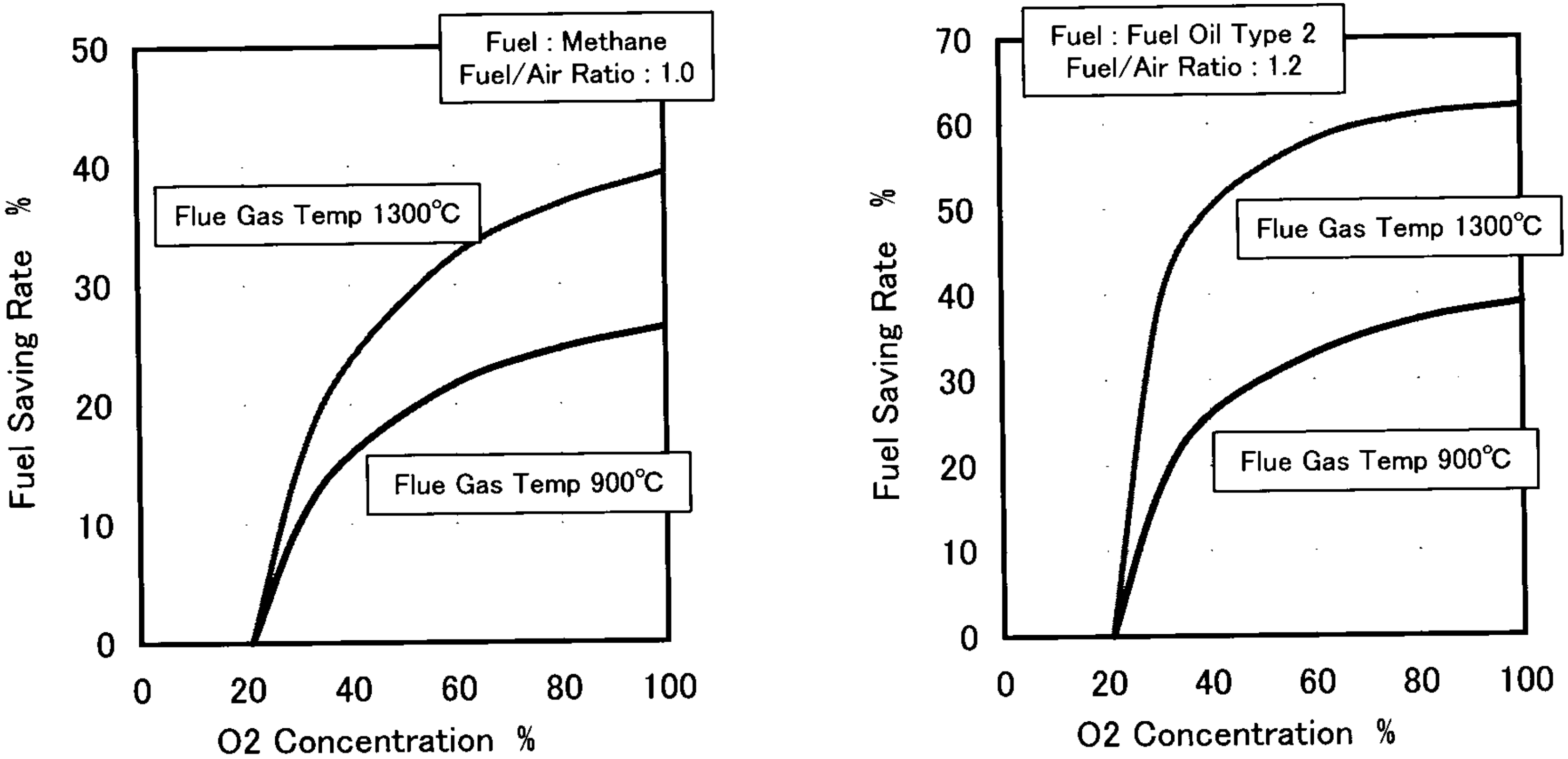
Oxygen Concentration in Comburent	Theoretical Comburent Volume	Theoretical Combustion Product m^3N/m^3N				Theoretical Flame Temperature
	m^3N/m^3N	CO_2	H_2O	N_2	Total	℃
100%	**2.00**	**1.00**	**2.00**	**0.00**	**3.00**	**2711**
80%	2.50	1.00	2.00	0.50	3.50	2652
60%	3.33	1.00	2.00	1.33	4.33	2561
50%	**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



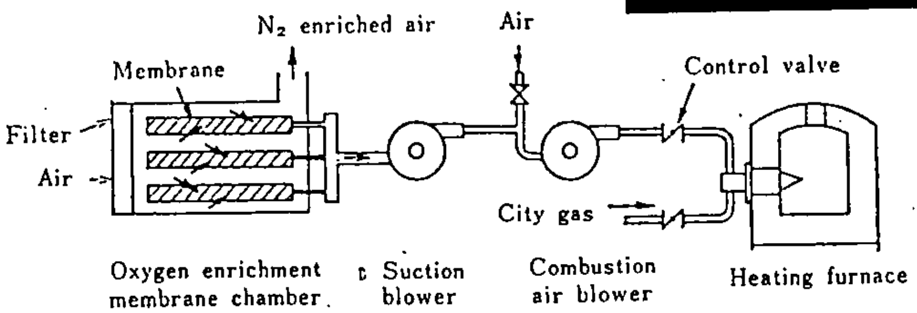


Theoretical Combustion Characteristics of Methane
in case of Changes in Oxygen Concentration



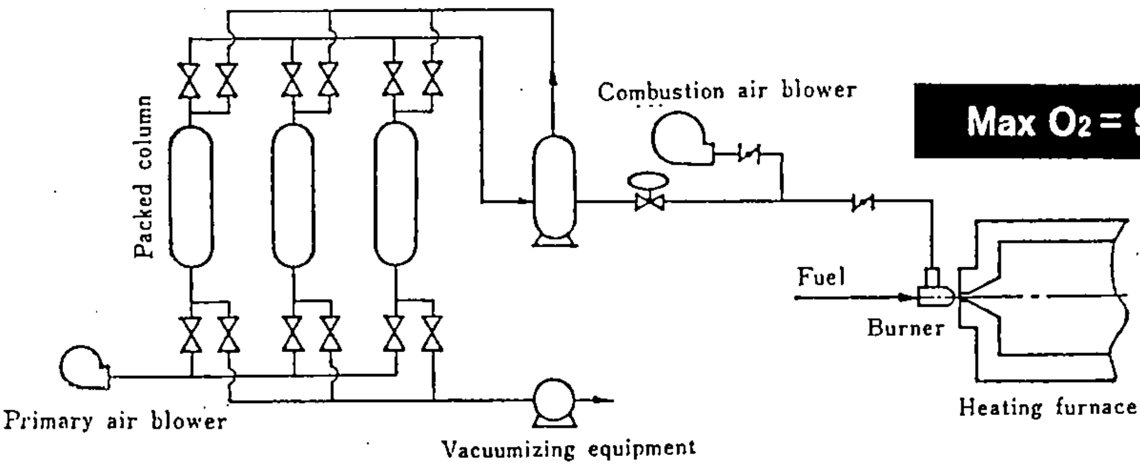
Fuel Saving Rate of Methane & Fuel Oil Type2 in case of Changes in Oxygen Concentration

Max O_2 = 40%



Membrane Method Oxygen Generator

Max O_2 = 95%



Pressure Swing Adsorption (PSA) Oxygen Generator

New Combustion Technology (3)

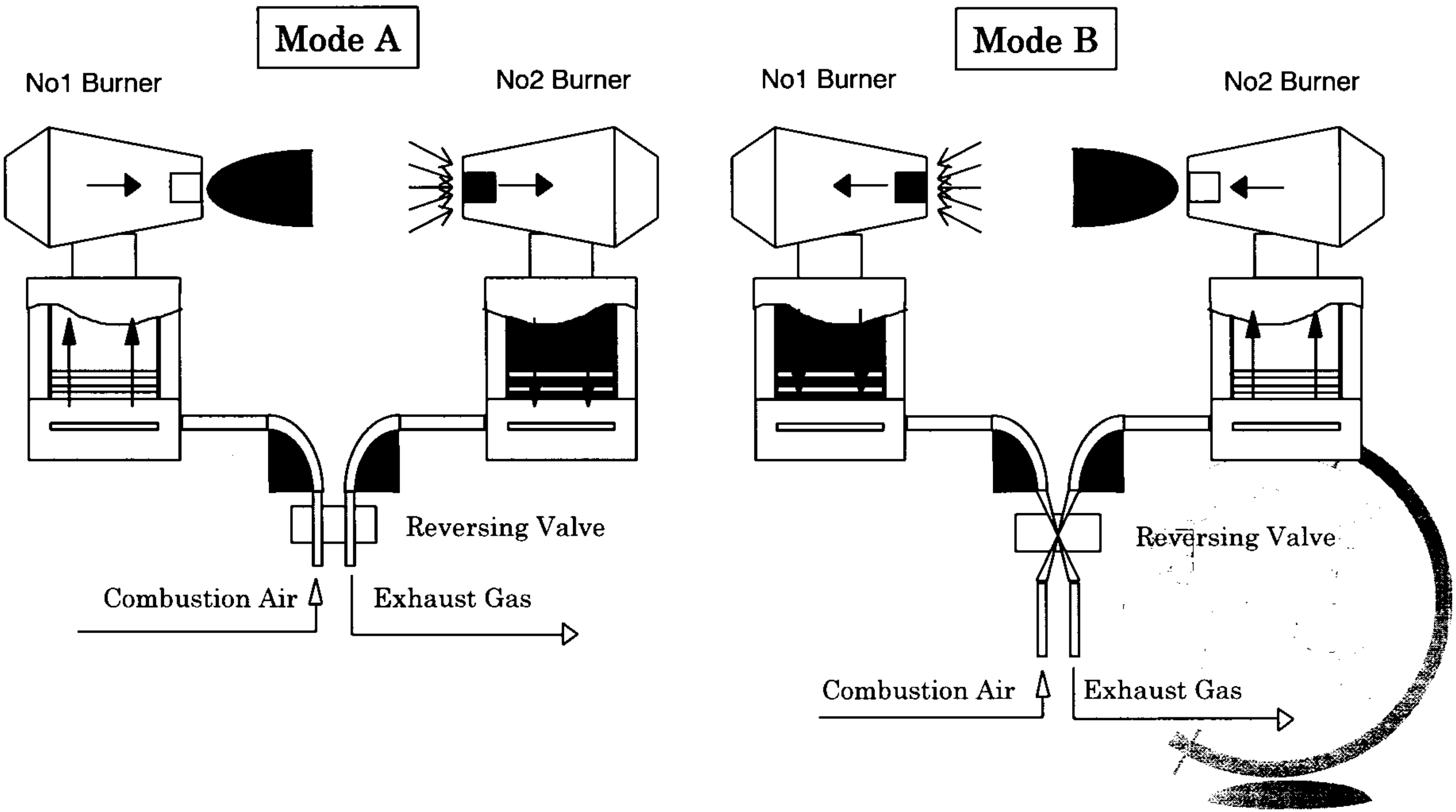
Regenerative Burner

- ✦ Advantages
  - ▪ Waste Gas Heat Recovery Max 90%

    Waste Gas Temp. : 1200℃

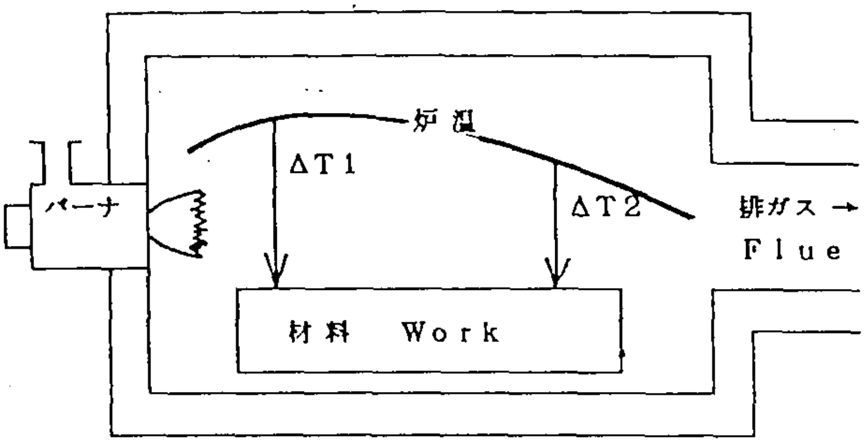
    Max. Preheated Air Temp. : 1080℃
  - ▪ Pulse Firing for Uniform Temp. Distribution
  - ▪ Heat Exchange in the Burners
  - ▪ Shorter Furnace Length

New Combustion Technology (3)
Control Logic of Regenerative Burner



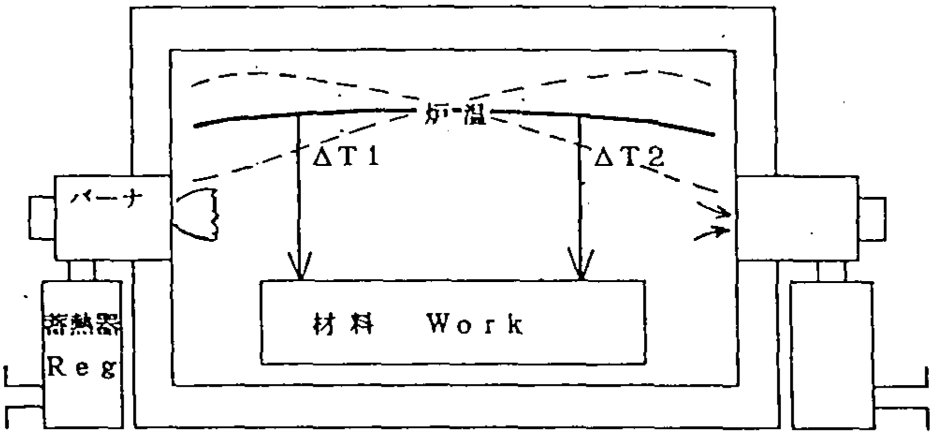
従来の燃焼炉

Conventional　　ΔT1>ΔT2



蓄熱式バーナを使用する燃焼炉

Regenerative Furnace　　ΔT1=ΔT2



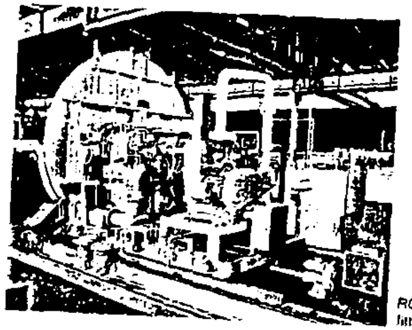
蓄熱式バーナの温度分布

Temp. Distribution by Regen. Burner

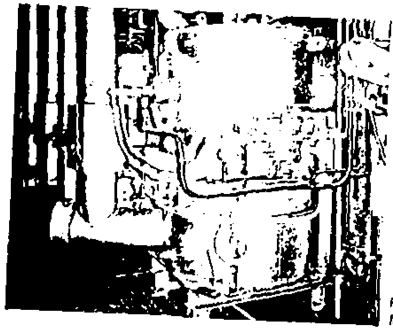
ChugaiRo

New Combustion Technology (3)

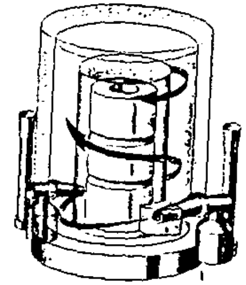
Application Examples of Regenerative Burner



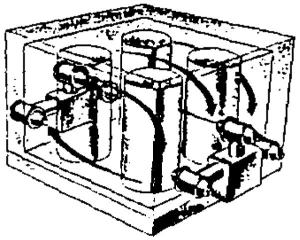
RCB regenerative burners fitted to a ladle preheater



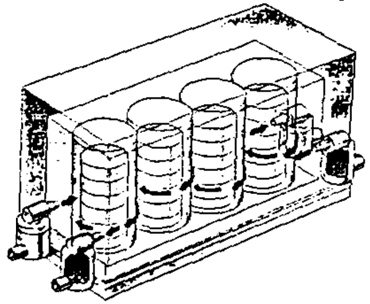
RCB regenerative burners fitted to a steel reheating furnace



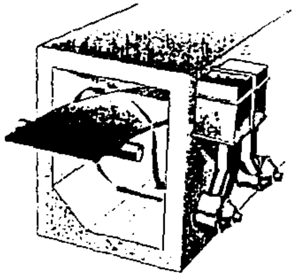
Bell type coil annealing furnace



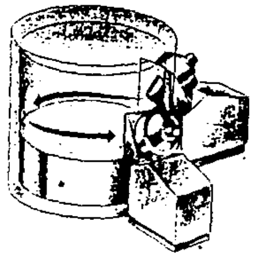
Cross fired coil annealing furnace



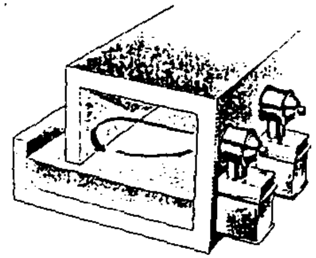
Corner fired coil annealing furnace



Catenary type continuous steel strip heat treating furnace



Round reverberatory aluminum melting furnace

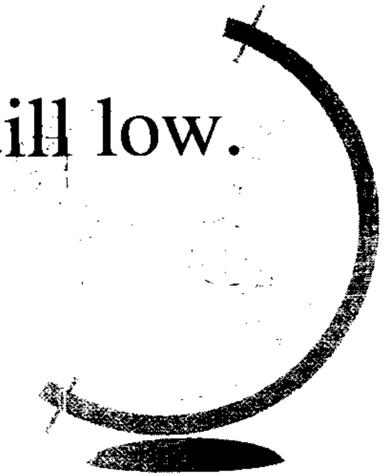


Front well type reverberatory alminum melting furnace

New Combustion Technology (4)

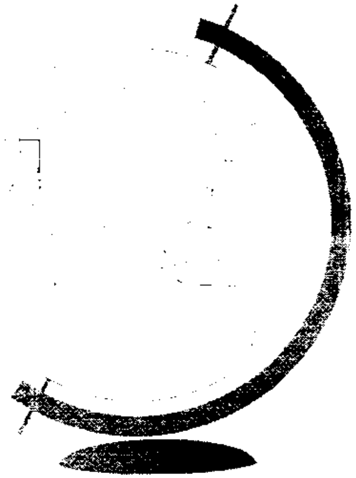
Computational Simulation of Combustion

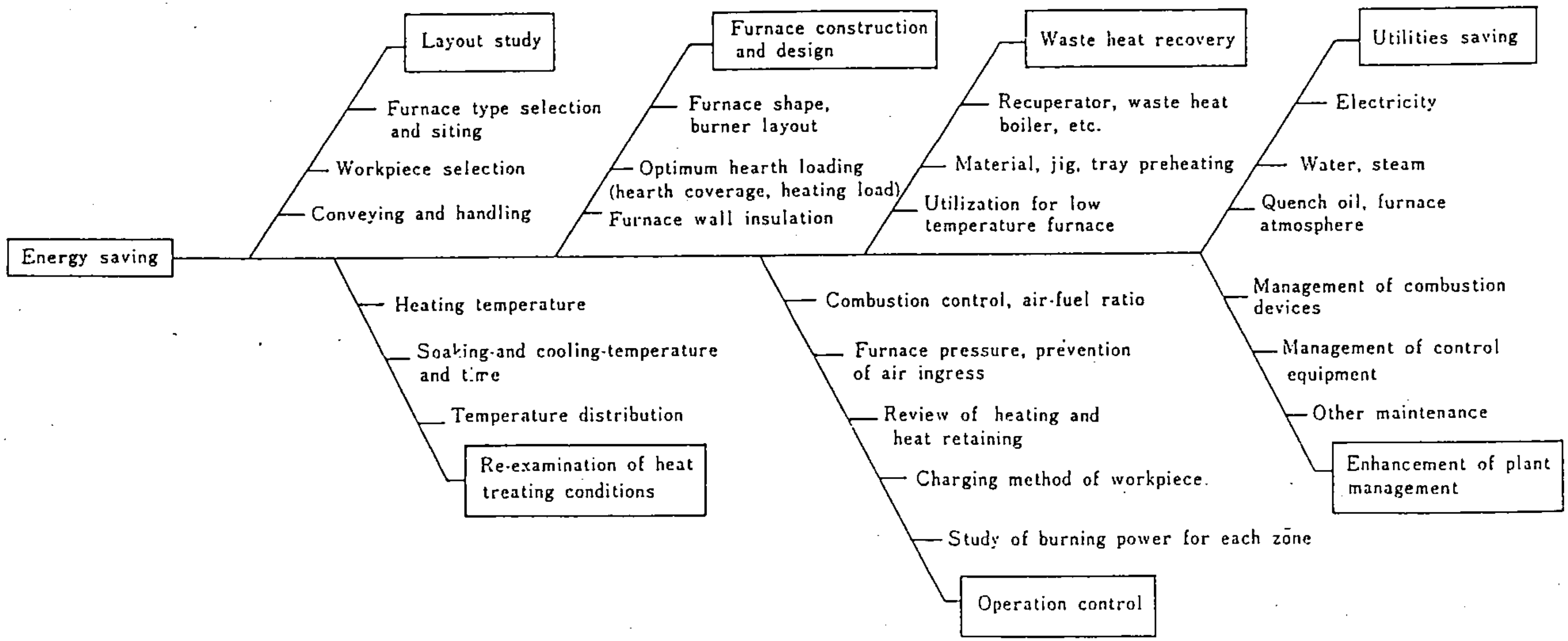
- ✦ Analysis Cords
  - ▪Fluent, Star-CD, etc...
- ✦ Simulated Results
  - ▪Distributions of Fluid Temperature, Fluid Flow and Gas Species.
- ✦ At present, accuracy of the results is still low. However, in the near future, it will be improved.



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

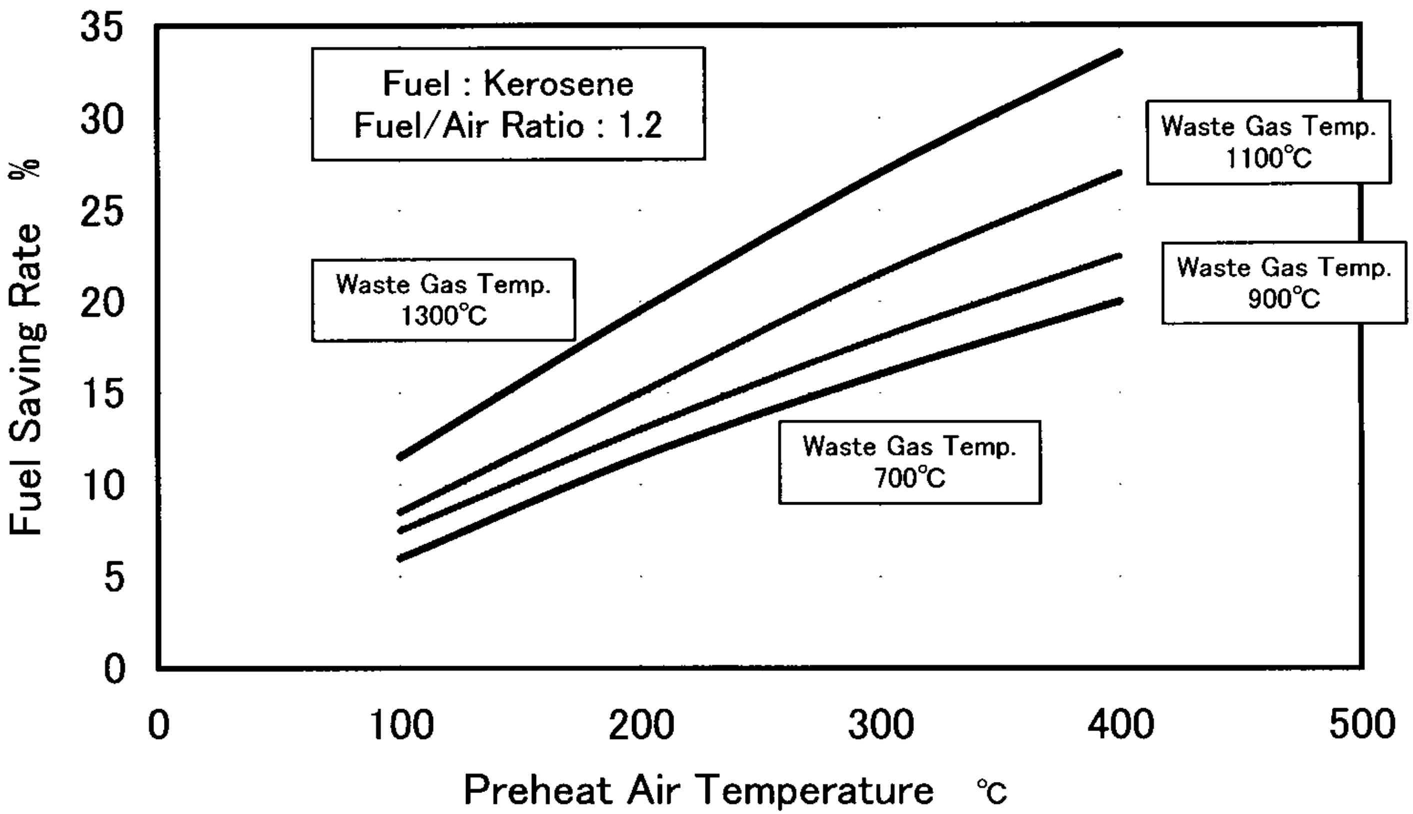
--- Heat Recovery from Flue Gas ---

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

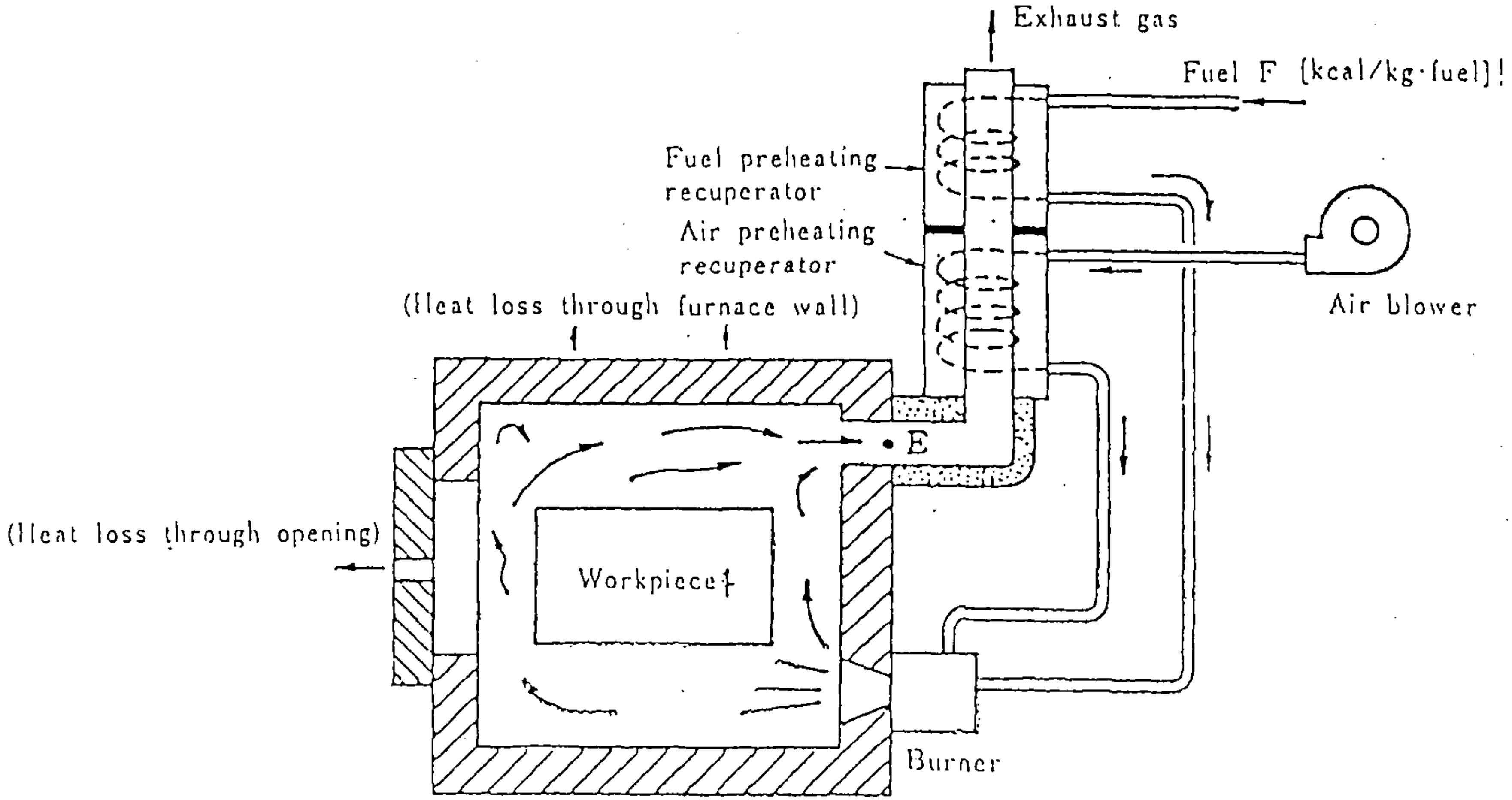
ex)
- Kerosene, Excess Air Ratio=1.2
- Flue Gas and Preheated Air Temp. = 900 and 300℃
- Fuel Saving Rate = 18.4%

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

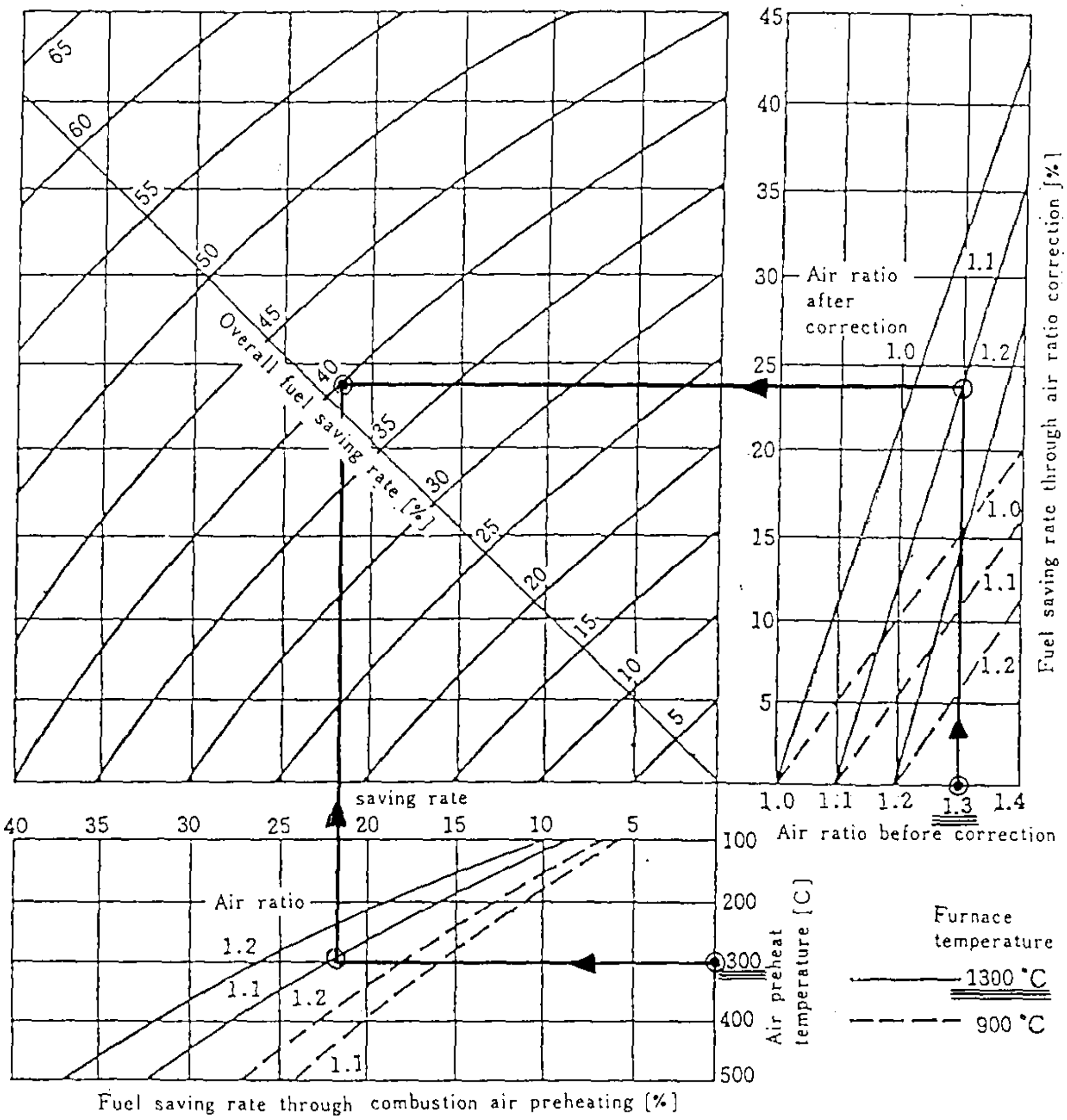
Table 7. Outline of Air Preheater



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.

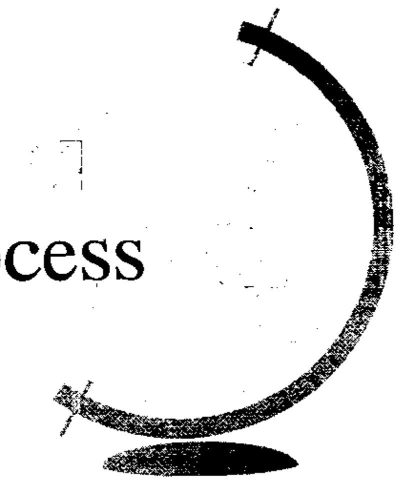
Combustion Technology for Low Environmental Pollution

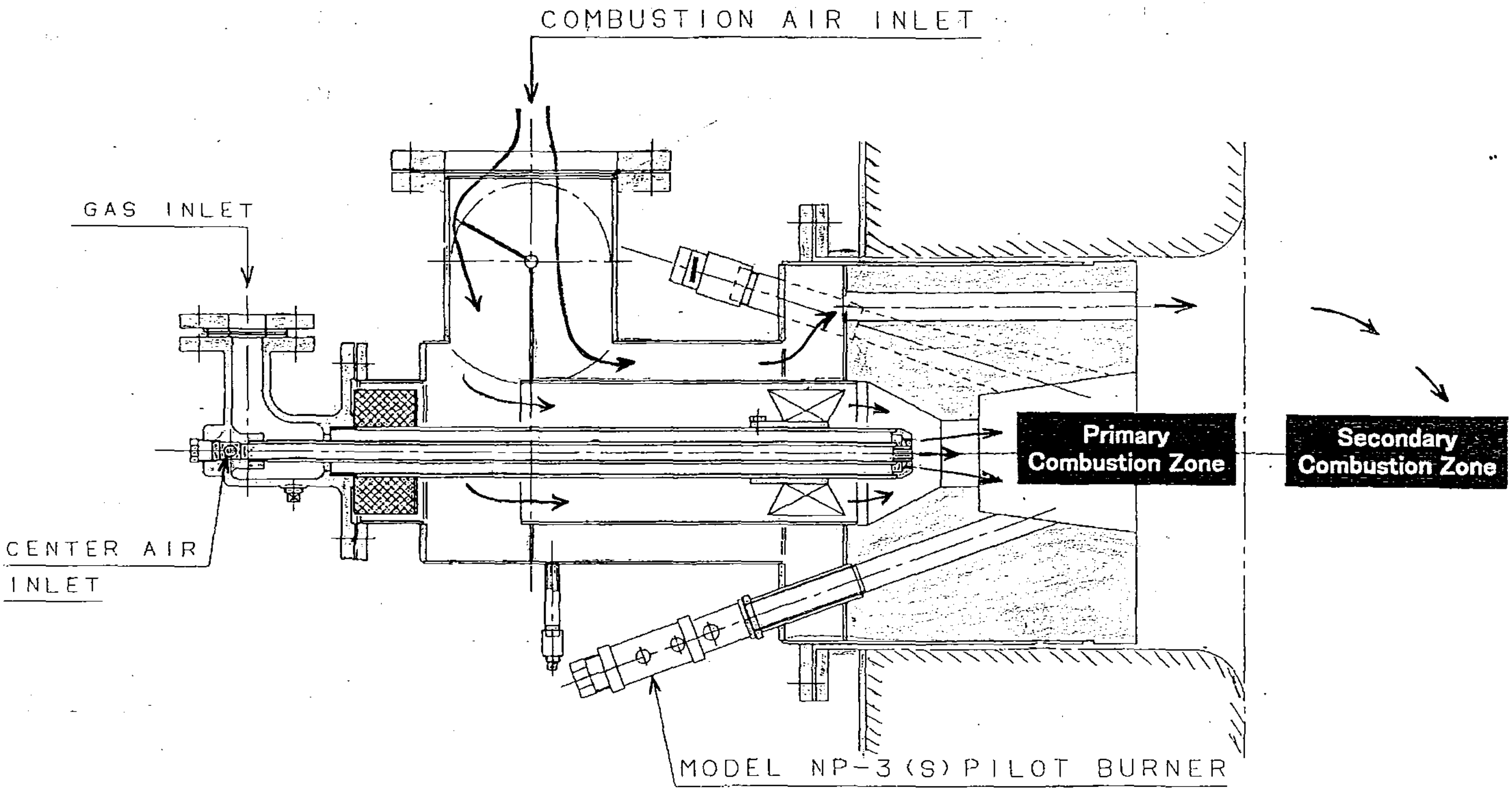
✦ Impact of NOx

NO_2 turn into photochemical oxidants, thereby giving rise to photochemical smog.

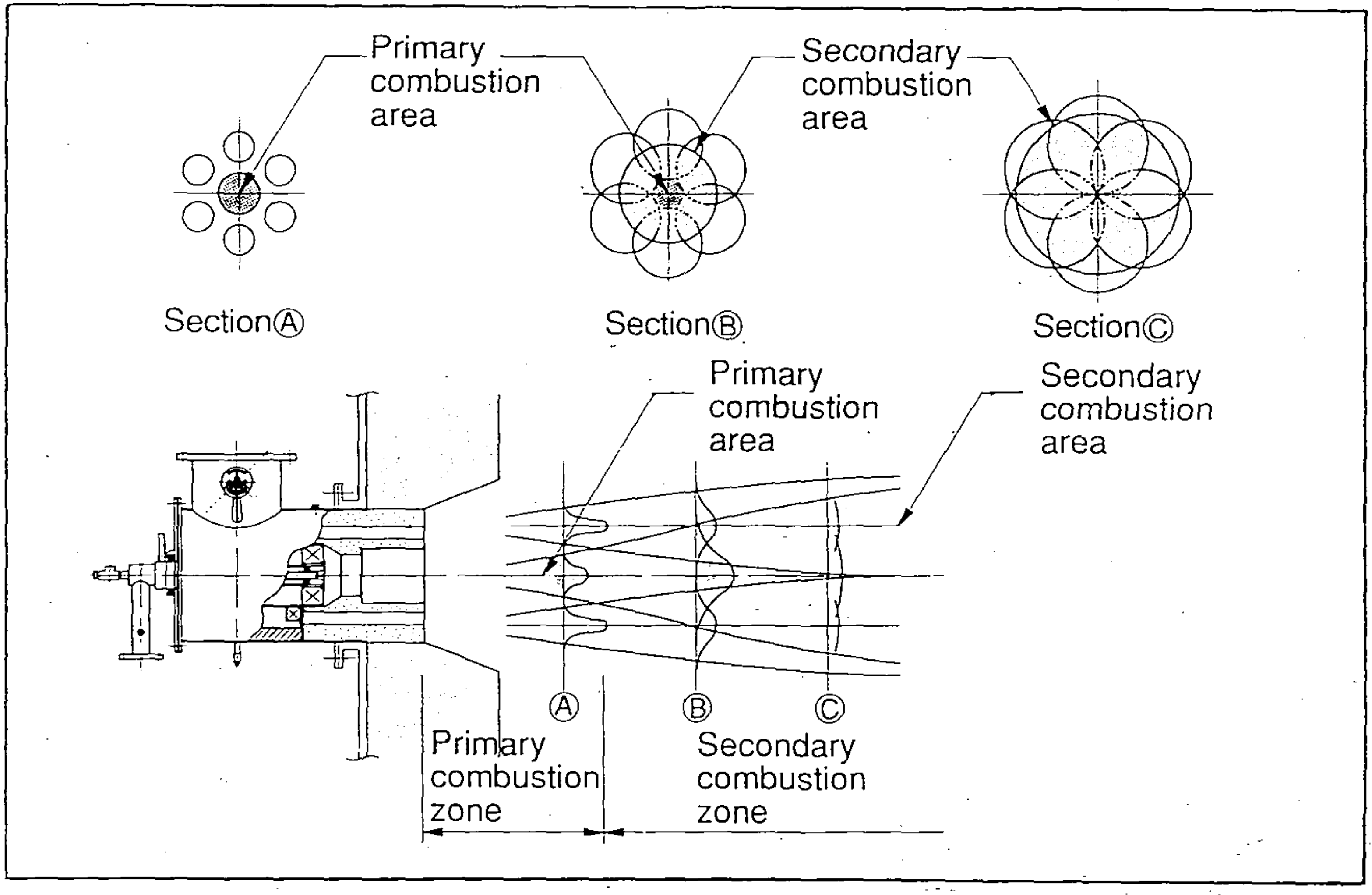
✦ NOx reduction measures

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

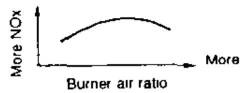
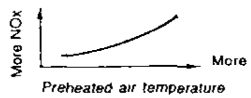
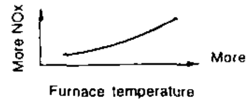
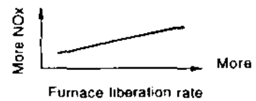
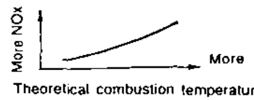
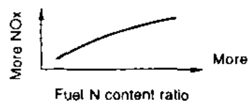
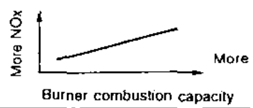




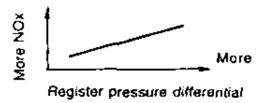
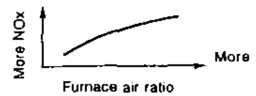
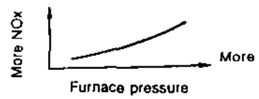
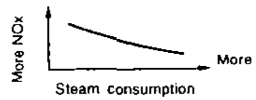
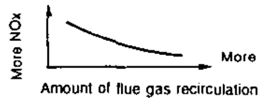
Type FHC High Turn Down Low NOx Burner



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)

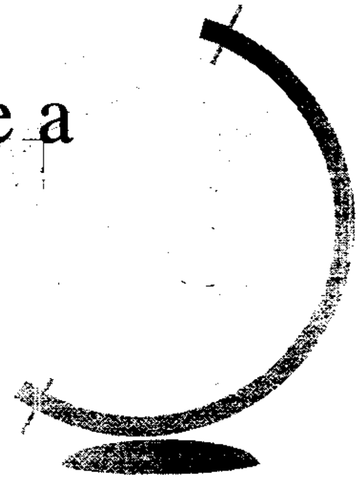
Relationship between Burner Operation Patameters and Amount of NOx Generated (2)

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.

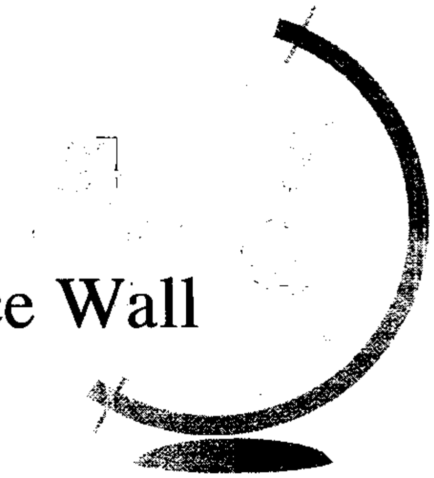


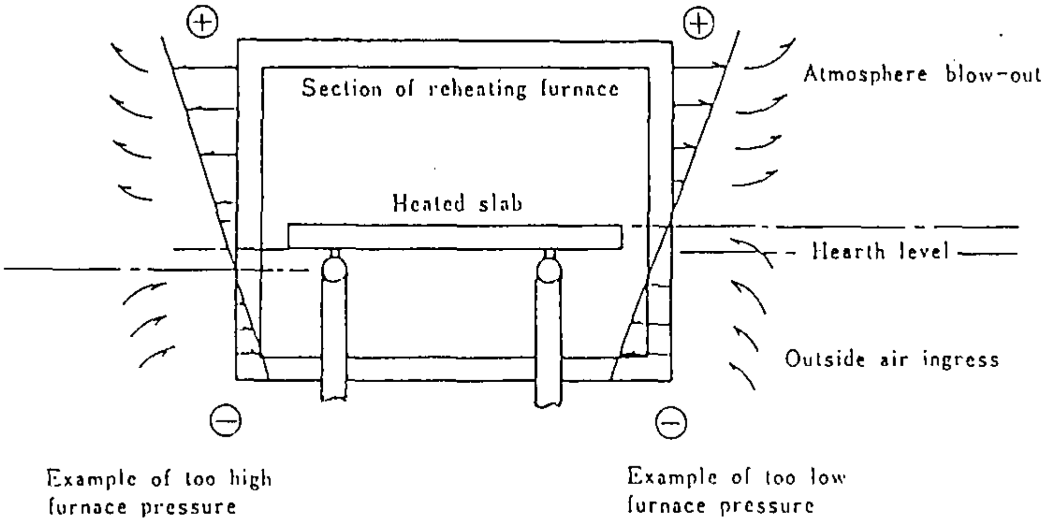
Combustion Technology for Low Environmental Pollution

- ✦ 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

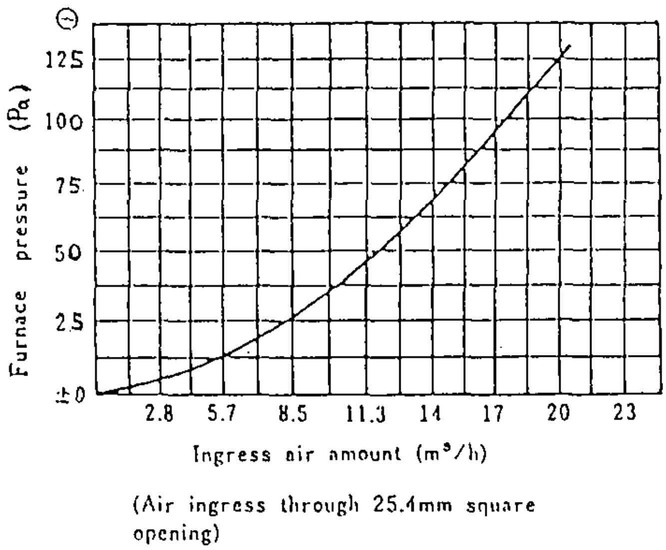
Industrial Furnace Conservation Techniques

- 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

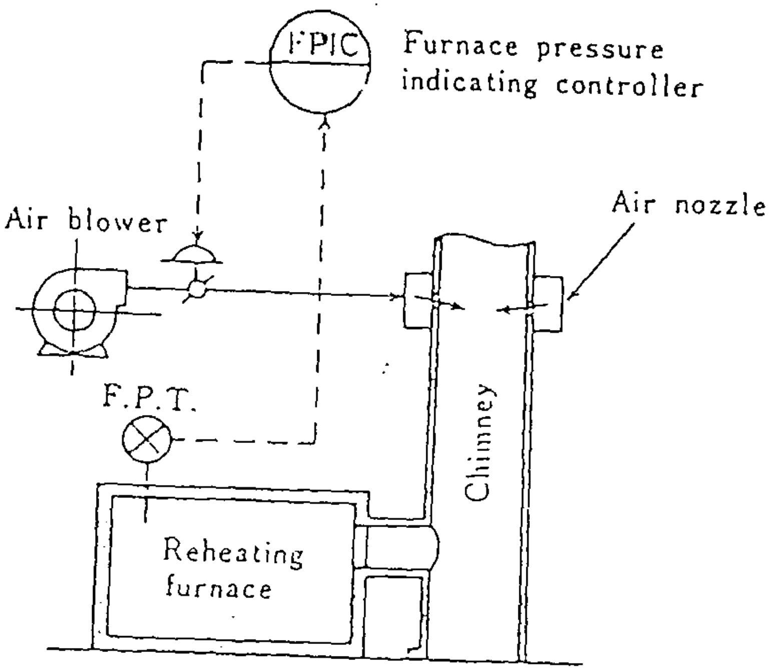




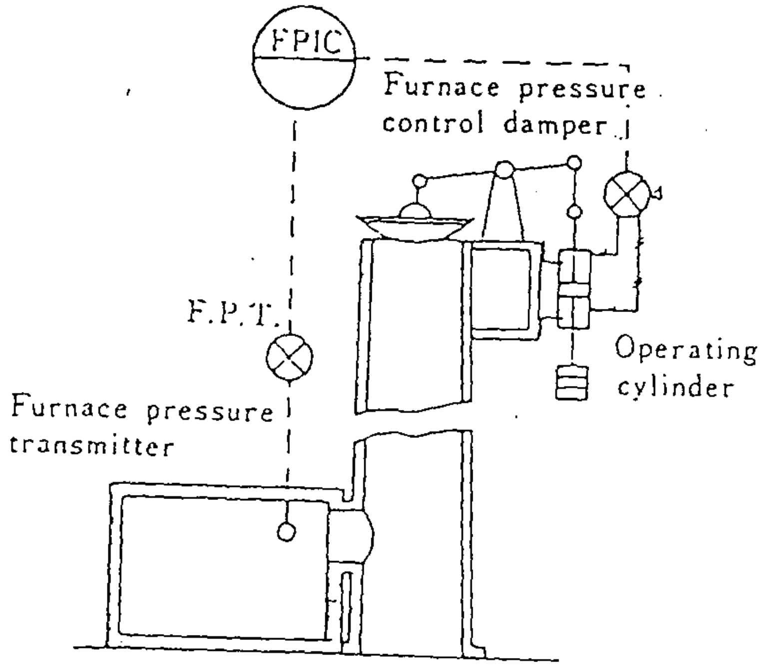
Air Ingress during Reheating Furnace Operation



Furnace Pressure vs Ingress Air Amount

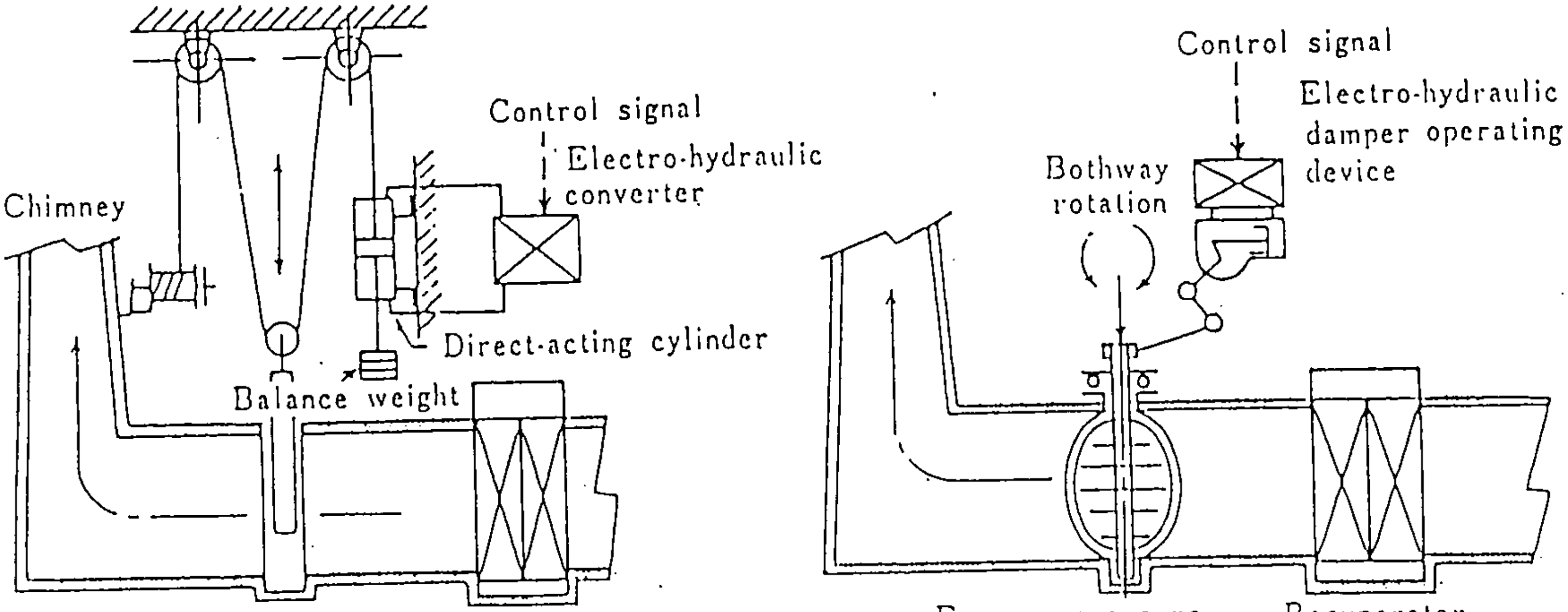


(a) Air curtain type



(b) Poppet valve type

Damper for Pressure Control



(a) Suspended slide damper

(b) Rotary (butterfly) type damper

Damper Configuration

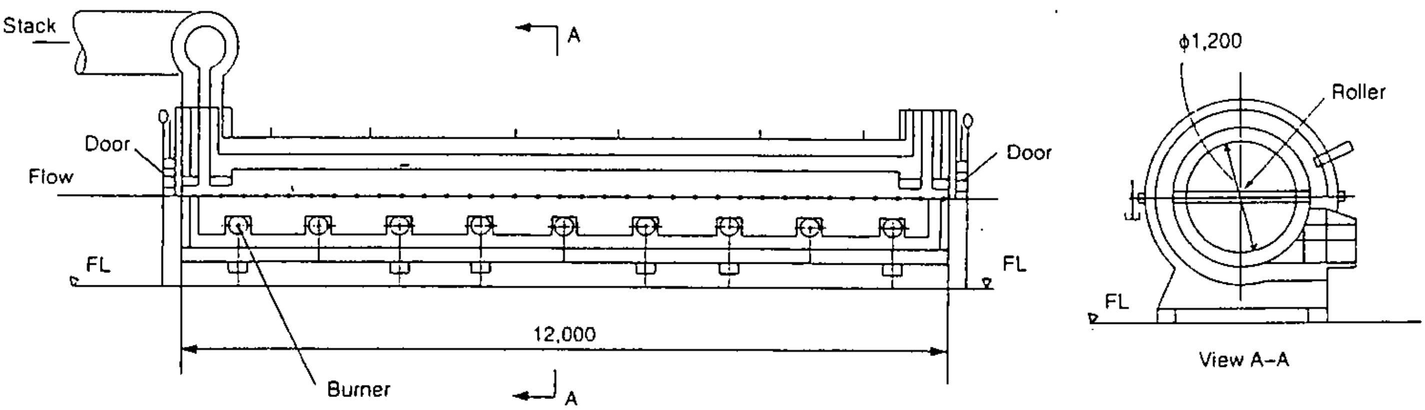
Case Study of ECCJ Factory
How to Save Energy

- ✦ 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℃
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

This furnace, called the roller furnace, is used for increasing the strength of steel rods by continuously quenching and hardening.

A simple specification is shown in the attached sheets. Steel rods are cut into a prescribed size, inserted in succession from the furnace inlet, and heated to 950°C. The heating capacity is 1000kg/h, and A heavy oil is used as fuel.

Contents of this heavy oil are shown below. The low heating value, theoretic excess air ratio and theoretic exhaust gas quantity are given here, but these can be easily calculated as follows.

A Heavy Oil

Contact C; 86% H; 13% S; 0.1% O; 0.7%
N; 0.03%

Equation

A Heavy Oil (1 kg); $\frac{0.86}{12}C + \frac{0.13}{1}H + \frac{0.001}{32}S + \frac{0.007}{16}O + xO_2$

$\rightarrow \frac{0.86}{12}CO_2 + \frac{0.12}{2}H_2O + \frac{0.005}{32}SO_2$

$x = \frac{0.86}{12} + \frac{0.13}{2\times 2} + \frac{0.001}{32} - \frac{0.007}{32} = 0.1040$

$0.1040 \times 22.4 = 2.330\ Nm^3/kg$ fuel

1) $A_0 = 2.330/0.21 = 11.09\ Nm^3/kg$ ful

2) $G_0 = \left(\frac{0.86}{12} + \frac{0.13}{2} + \frac{0.001}{32} + \frac{0.0003}{28}\right) \times 22.4 + 11.09 \times 0.79$

$= 11.82\ Nm^3/kg$ fuel

3) $H_l = 42.11$ MJ/kg

For combustion, while the fuel is ON-OFF controlled so that the wall temperature is 1000°C at the furnace center, the average excess air ratio is very high as 1.6 because the air flows in even during the OFF time.

The exhaust gas, at 1000°C, is discharged from the gas duct provided before the furnace inlet. When calculating a heat value that the exhaust gas takes, as shown in Table 3.9, the exhaust gas's specific heat varies by gas content and temperature. Strictly speaking, it needs to be calculated for each case.

However, here it is calculated based on 1.381 $KJ/m^3N°C$ and constant.

The heat insulation configuration is firebrick SK33 115 mm + insulating firebrick B6

115 mm. Their mean heat conductivity and the furnace's outside and inside surface temperature are also shown in the chapter of insulation including examples of energy conservation type. Strictly, the heat conductivity is also a function of temperature, and porous materials have more of this tendency. However, here it is also considered as a constant.

This furnace is cylinder shaped. When calculating a heat loss from furnace wall, the heat transfer calculation is conducted using formulas applicable to the cylinder. Additionally, heat loss at the inlet and outlet are calculated using formulas for plane boards. However, here you may use the value which already calculated.

A furnace inevitably has openings including the inlet and outlet, however, radiation loss, air invasion and blow out of furnace gas from these openings should be avoided as much as possible. These factors can be calculated by the area of opening, wall thickness and furnace pressure.

Invasion of air and blow out of furnace gas, in particular, should be given consideration when examining whether to provide a damper control or not. However, here these are considered as negligibly small compared with other heat losses.

Scale production largely depends on the furnace temperature and the oxygen concentration of furnace gas.

Reduction of excess air ratio is the first to be considered in terms of energy conservation. In conducting the present calculation, it is assumed that the excess air ratio can be reduced to 1.2. And, in this case, scale production is supposed to be 70%.

In case of iron the produced scale consists of FeO, Fe_3O_4 and Fe_2O_3 and for each the producing heat and specific heat are different. However, if a scale analysis is not conducted, it is specified in the JIS that the producing heat may be supposed to be 5.588 MJ/kg, the specific heat 0.90 KJ/kg°C, and the iron content in scale as 75.5%.

The specific heat of steel varies itself by temperature. Especially, as the steel involves phase transformation, the specific heat increases a lot near the phase transformation. Thus, while a table of specific enthalpy as shown in Table 5.1 should be used for strictness in cases of heating exceeding the phase transformation point of 727°C, here 0.699 KJ/kg°C is taken as a mean specific heat.

Using these values, heat balance of the current furnace is calculated as the attached sheets.

Next, to examine effects of various energy saving measures to this furnace, heat balance is calculated for each. As measures first to be applied, reduction of excess air ratio, enhancement of heat insulation, recovery of exhaust heat, etc. are considered. and each follows premises as shown below.

Excess air ratio is reduced from 1.6 to 1.2, heat insulation is enhanced by veneering the furnace's inner surface with ceramic fiber, and combustion air is preheated to 600°C by heat recovery.

Since the fuel consumption X is unknown, first it is determined based on an assumption that the input heat equals the output heat, and the value is substituted for further calculation.

As an example, the result of simultaneously applying all measures is shown. To examine the contribution of each measure, results of individual measures are to be calculated by yourself.

Combinations to be examined are the following.

1. excess air reduction (auto combustion system)
2. heat insulation enhancement
3. heat recovery
4. combination of above 1., 2., and 3.

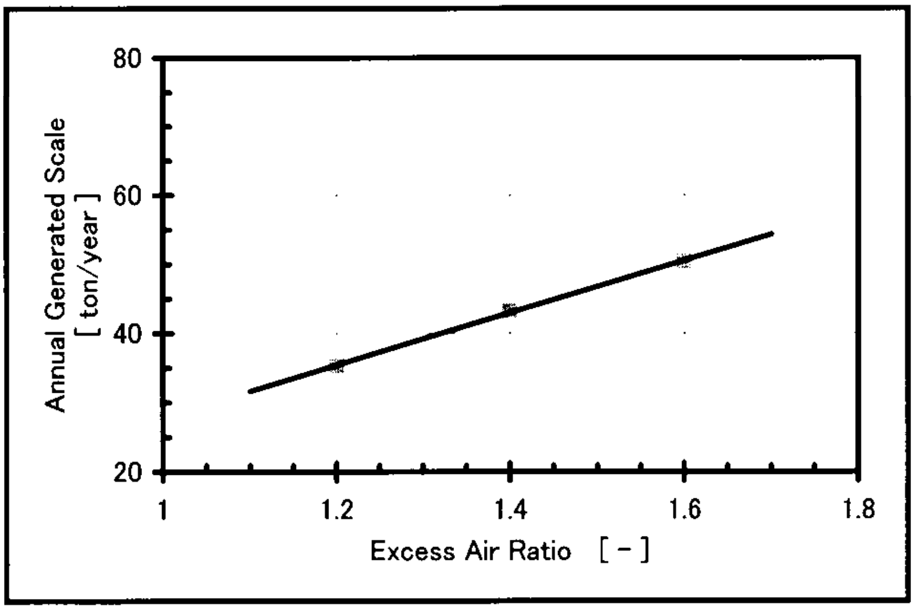
Veneering Thickness (mm)	0 (Existing)	25	50	75	100
Surface Tem. Cylindrical Wall (℃)	134	113	100	90	82
Surface Tem. Vertical Wall (℃)	135	118	106	97	91
Wall Heat Loss Cylindrical Wall (MJ/h)	356.9	262.8	206.2	168.5	141.5
Wall Heat Loss Vertical Wall (MJ/h)	14.4	11.3	9.3	7.9	6.9
Total Heat Loss (MJ/h)	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 * Total Fe in Scale * Capacity * Heat of Oxidizing Reaction (Fe)
7 kg/ton * 0.755 * 1.0 ton/h * 5.588 MJ/kg

Output Heat Total 2612 MJ/h

3) Material's Sensible Heat 637.65 MJ/h

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

4) Exhaust Gas Loss 1513.11 MJ/h

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

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

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

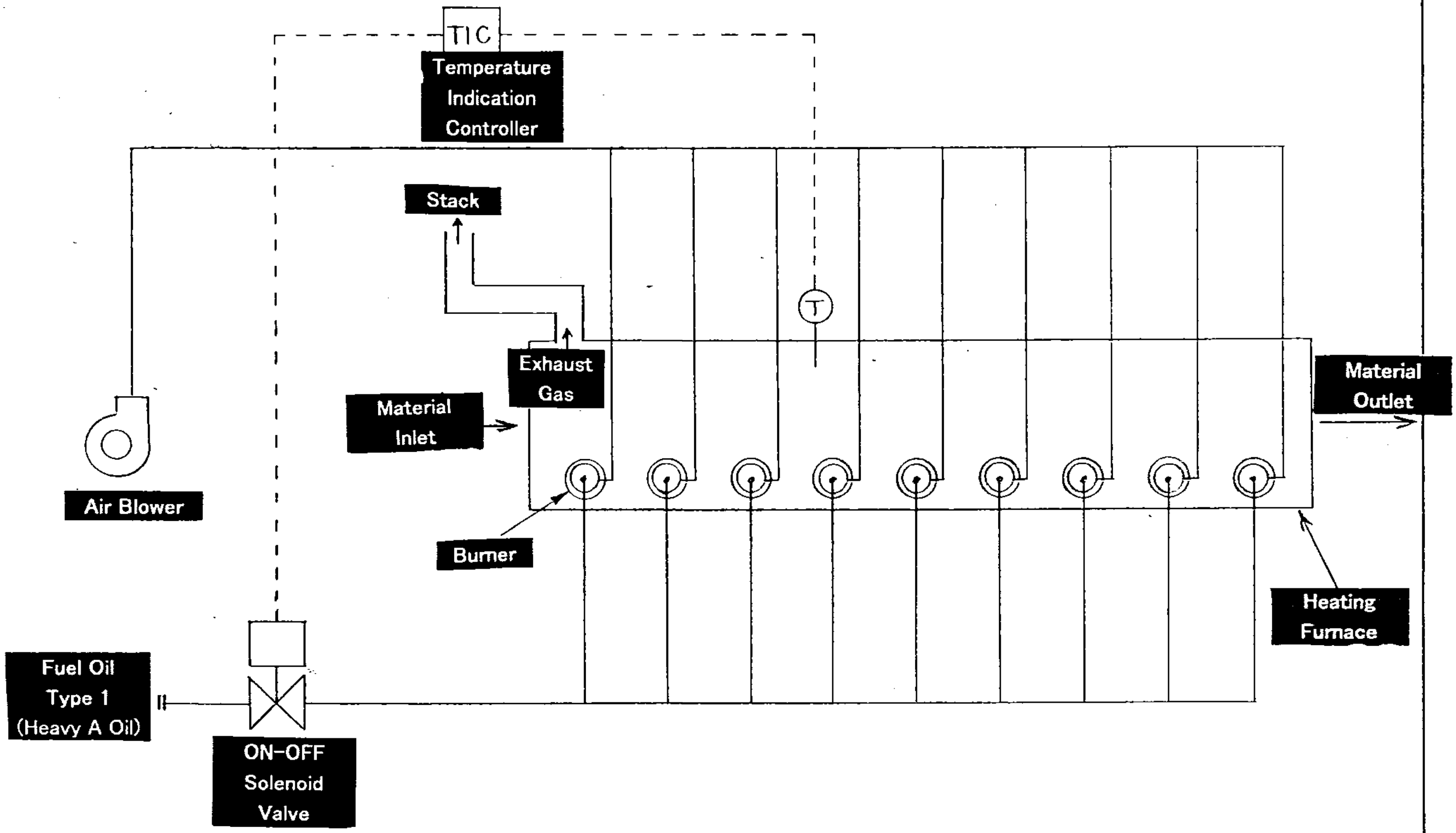
Heat Loss from Cylindrical Wall + Heat Loss from Vertical Wall
356.90 MJ/h + 14.44 MJ/h

6) Heat taken by Cooling Water 83.72 MJ/h

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

7) Scale's Sensible Heat 5.78 MJ/h

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



Current Flow Sheet

CHUGAI RO CO.,LTD.

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 Plywood Ring 25mm 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