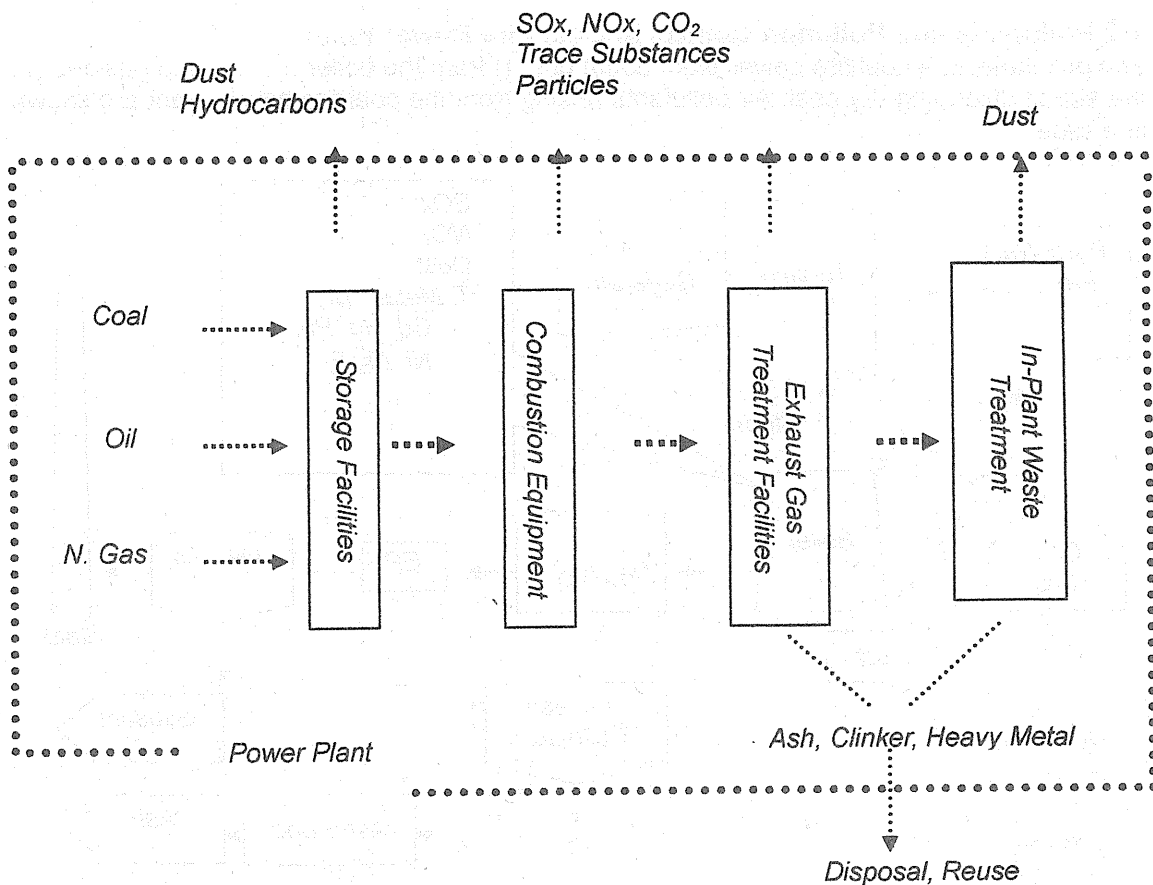


# I .Thermal Power Plant

## 1. Air Pollution in Thermal Power Plant

### 1-1 Pollutants Emission

In the thermal power plant, coal, oil or natural gas (N Gas) are generally used as fuel for a boiler to drive the turbine generator. In the processes of thermal power, pollutants such as SO<sub>x</sub>, NO<sub>x</sub>, CO<sub>2</sub>, dust, hydrocarbons, and trace substances are generated and waste materials are reused or disposed as shown in this slide.



Concrete removal methods for these pollutants except CO<sub>2</sub> are described respectively after page 2.

Among the global environmental problems causing worldwide controversy in recent years, "global warming effect" and "acid rain" are associated most intimately with the air pollution problems of thermal power plants.

For the controversial global warming, the greenhouse effect gases are carbon dioxide (CO<sub>2</sub>), methane (CH<sub>4</sub>), nitrous oxide (N<sub>2</sub>O), and etc., and it is presumed that CO<sub>2</sub> resulting from fossil fuel combustion has a substantial influence on this problem. This global warming problem has not been clarified yet; its causal relations and measures are not yet perfectly solved scientifically for us to sustain our level of economic activity.

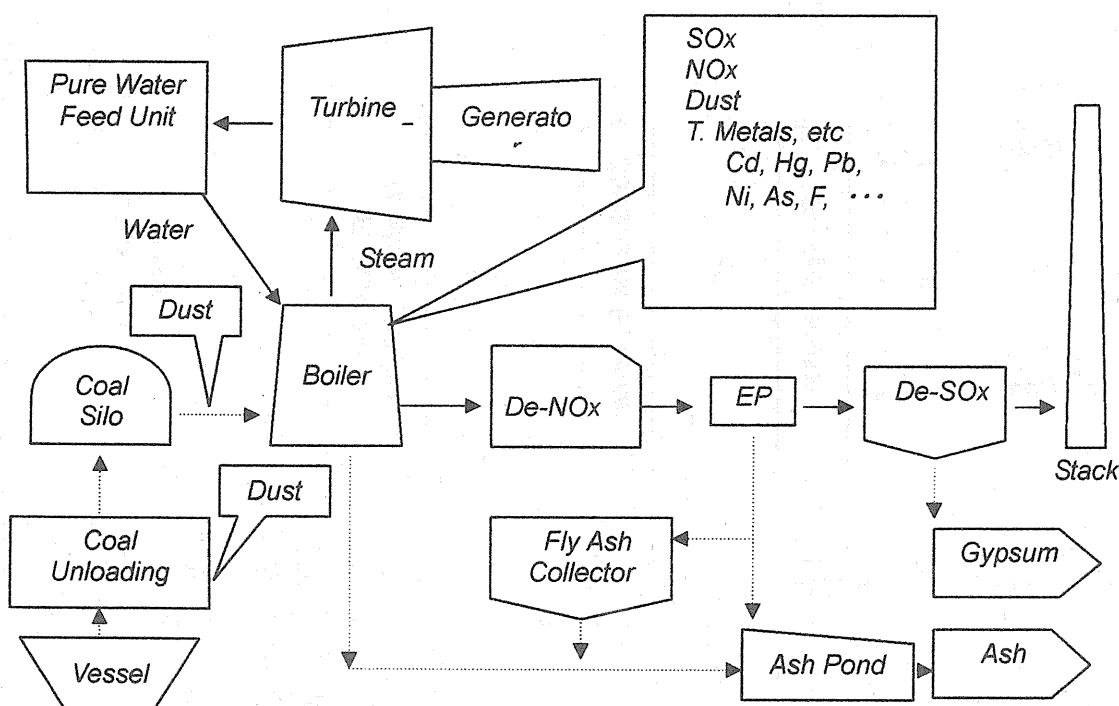
The global warming is an issue that nations will deal with and that emission of green house gases will be lowered or sequestered as envisioned in the Kyoto Protocol.

Regarding the acid rain problem, various countermeasures are described in slides especially in the section of SOx reduction technology.

For the detail information, refer to the pages at P.71~76 (Japanese version) or E.3~8 (English version) of "Air Pollution Control Measure Technology in Thermal Power Plant", Global Environment Centre Foundation, March1997" under the supervision by Air Quality Management Division, Environment management Bureau, Ministry of the Environment, Government of Japan.

### 1-2 Pollutants and Pollution Control in Coal Fire Power Plant

The pollutants in a coal fire power plant come out (1) from the boiler mainly, and besides (2) the site of unloading dry coal. Air pollutants arising from the coal fire power plant are shown in a slide.



During the handling of coal:

At fuel storage yard, dust scattering during coal unloading and spontaneous combustion of coal particles should be taken into care. These are; coal dust scattering from coal hoist and outdoor coal storage yard, spontaneous combustion in coal storage yard, and coal dust explosion in indoor coal storage yard.

Air pollutants also arise during the transportation from storehouse to boiler and in the pulverizing process.

At fuel combustion:

SOx, NOx, dust, trace metals, etc such as cadmium (Cd), mercury (Hg), lead (Pb), nickel (Ni), arsenic (As), fluorine (F), etc. are generated.

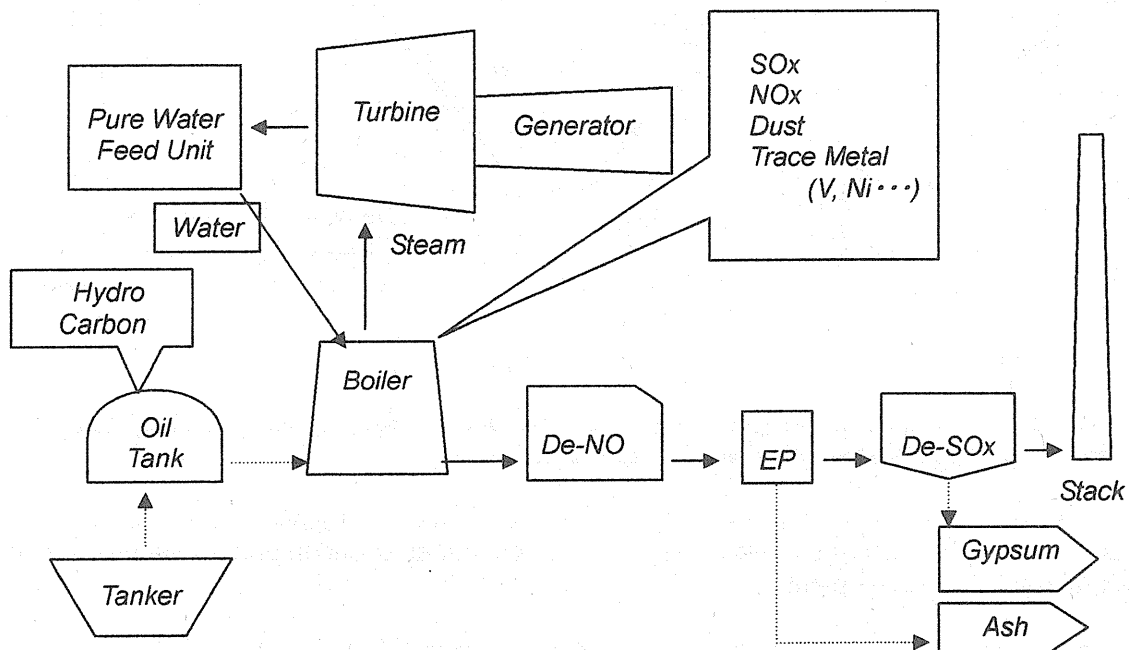
The exhaust gas from a coal fire boiler is sequentially led to denitrification equipment,

electrostatic precipitator, desulphurization equipment, and then to stack. The pollutants are recovered as forms of ash and gypsum.

For the detail information, refer to the pages at P. 73~76 or E.4~8.

### 1-3 Pollutants and Pollution Control in Oil Fire Power Plant

The pollutants in an oil fire power plant come out from (1) the boiler mainly and merely from (2) the oil storage tanks. Air pollutants arising from the oil fire power plant are shown in a slide.



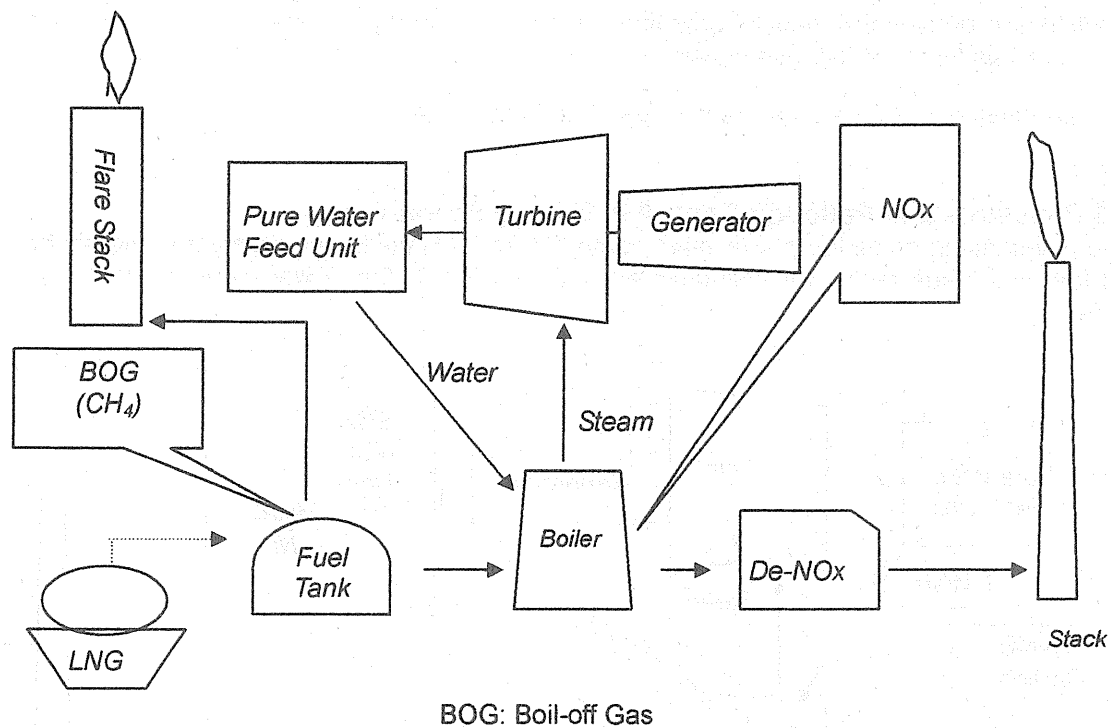
At oil storage yard, vapor from storage tank comes out, of which the compositions are hydrocarbons. During the handling of oil, no air pollutants arise in the processes unlikely coal. At fuel combustion, SO<sub>x</sub>, NO<sub>x</sub>, dust, trace metals such as vanadium (V), nickel (Ni), etc. are generated.

The exhaust gas from an oil fire boiler is sequentially led to denitrification equipment, electrostatic precipitator, desulphurization equipment, and then to stack. The removed pollutants are recovered as forms of ash and gypsum.

For the detail information, refer to the pages at P. 73~75 or E.4~8.

### 1-4 Pollutants and Pollution Control in Gas Fire Power Plant

The pollutants in a natural gas fire power plant come out from (1) the boiler mainly and merely from (2) fuel tanks. Air pollutants arising from the natural gas fire power plant are shown in a slide which is very simple unlike to coal fire power plant or oil fire power plant. At oil fuel tank yard, boil -off gas such as methane (CH<sub>4</sub>), etc. comes out.



During the handling of natural gas, no air pollutants arise in the processes unlikely coal. At natural gas combustion, only NO<sub>x</sub> is generated.

The exhaust gas from natural gas fire boiler is generally led to denitrification equipment and then to stack. No waste materials are generated from the air pollution abatement process at natural gas firing power plant.

For the detail information, refer to the pages at P. 73~76 or E4~8.

## 2. Measures against Fuel

### 2-1 Coal Fire Power Plant

For construction of a coal fire power plant with outdoor coal storage, a coal dust scattering simulation is carried out in advance in order to predict the amount of coal dust scattering to peripheral areas. The height of windshield fence around the coal storage yard, installation location and the moisture content control for coal are studied, and consequently no coal dust will affect environmental preservation.

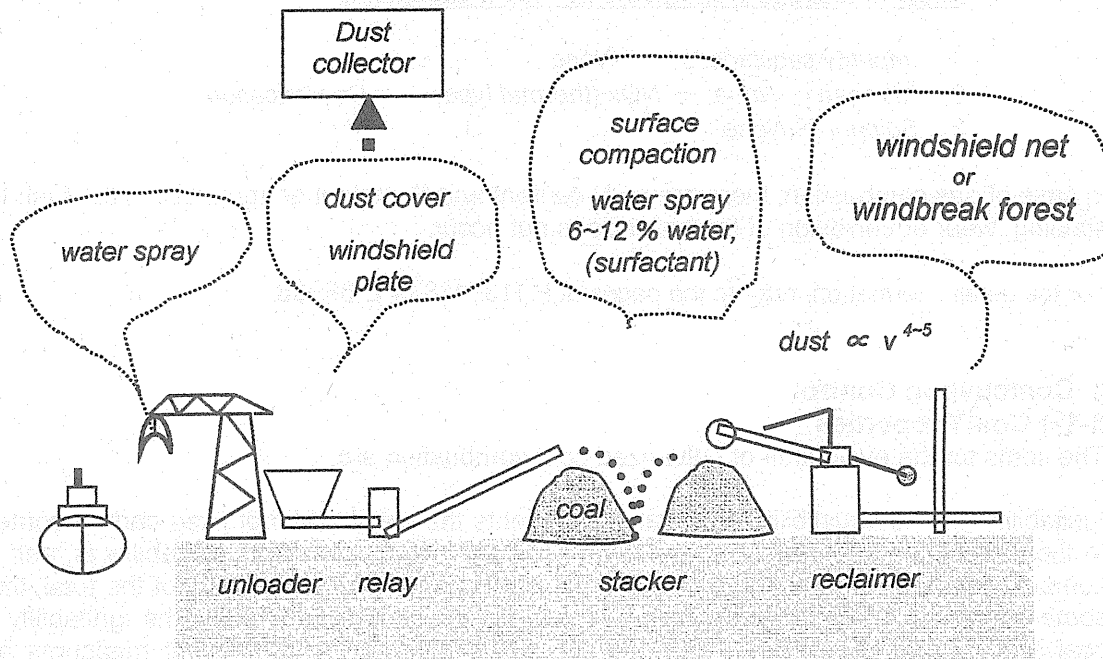
Water spraying has the effect of controlling scattering of coal dust by increasing the moisture content in coal. Some coals are highly water repellent and water spraying has only a small dust proofing effect. In this case, the coal dust preventive agent is added.

Windshield fence, windshield net, and windbreak forest are useful to prevent the scattering of dust, because the scattering coal dust volume is said to be proportional to the fourth to fifth power of the average wind velocity (V).

The hermetically sealed conveyer, windshield plate mounted conveyer, dust collector, and surface compaction of storage coal are also effective methods. Recently continuous type unloaders have been popularly employed in view of coal unloading efficiency and environmental measures. For an indoor coal storage, which is not necessary to be concerned with dust as for an outdoor stock pile, the dust collection and ventilating

equipment for prevention of coal dust explosion become necessary.

The conceptual figure in the slide shows the coal handling processes, air pollutants sources, pollutants, and pollution control methods.



For the detail information, refer to the pages at P.92~97 or E.27~28.

## 2-2 Oil and Gas Fuel Power Plants

In case of oil fuel, exhaust gas components that pose environmental problems are nitrogen oxides (NO<sub>x</sub>), sulphur oxide (SO<sub>x</sub>), dust and soot and boiler corrosive elements. Residual carbon content is a coke-type carbon residue produced when samples are subject to thermal decomposition with air supply cut. Residual carbon is liable to turn into soot and dust.

### Effect of fuel oil properties on exhaust gas quality

1. Residual Carbon → Soot, Dust → Dust collection
2. Nitrogen → NO<sub>x</sub> → Denitrification
3. Sulphur → SO<sub>x</sub> → Desulphurization
4. Ash → Pressure drop, Heat transfer broke,  
Mechanical Wear, Corrosion → Maintenance

Nitric content amounts to about 0.01~0.6 wt % in the case of heavy crude oil. During combustion, part of the nitric content is exhausted as NO<sub>x</sub>.

Fuel oil contains sulphur as some form of sulphur compounds or another. When they are burned, they become sulphur oxide (SO<sub>2</sub>), and part of it is further oxidized to sulphuric anhydride (SO<sub>3</sub>). If the temperature of combustion exhaust gas is lowered below the dew point, SO<sub>3</sub> combines with moisture content within the exhaust gas, becoming sulphuric acid (H<sub>2</sub>SO<sub>4</sub>), which brings corrosion to steel structure.

Ash is contained in fuel oil, although its volume is small. The ash includes sodium,

potassium, iron, silicon, vanadium and nickel. On the occasion of combustion, these attach and accumulate on gas paths, causing the increase of pressure loss, blocking of heat transfer, mechanical wear and chemical corrosion.

Effect of fuel gas properties on exhaust gas quality

1. Impurity substances .....None
2. Nitrogen ...None → NO<sub>x</sub> (thermal type) → Denitrification
3. Sulphur ...None

In case of gas combustion, there are no N content and S content or impurities in the fuel, the staining, wear or corrosion of the boiler does not occur.

For the detail information, refer to the pages at P.113~118 or E.58~66.

**3. Combustion Control**

**3-1-1 Coal Properties**

The items for the evaluation of pulverized coal combustion are:

Ignitability and combustibility; Fuel ratio represents the weight ratio of fixed carbon content to the volatile content. Generally, the higher fuel ratio is, the lesser its ignitability is, and its combustion speed also tends to be slow. Volatile content is less than 20% of the total, then some steps for stabilized ignition are necessary. Ignitability index show the ignitability of coal itself. If it is 35 or less, it is generally some ignitability improvement measures are necessary. Button index shows for the possible adhesion of pulverized coal to the burner nozzle, etc. As for coal with a button index of more than 6 or 7, particular steps are necessary to prevent the problems.

Effect of Coal Properties on Pulverized Coal Combustion

<u>Ignitability &amp; Combustibility</u>	<u>optimum range</u>	<u>effects in case of off-spec.</u>
Fixed-C / volatile content	<2.5~3.0	increase of non-burn loss
Volatile content	>20%	unstable ignition
Ignitability Index	>35	hard ignition
Button Index (viscosity)	<6~7	clogging, adhesion
<u>Grindability</u>		
Proper size	50~100 μm	increase of non-burn loss
Dryness	H <sub>2</sub> O < 20 %	lowering mill performance
<u>Slagging</u>		
Ash Melting Temp.	>1,300 °C	} slagging
Ash Alkaline Ratio	<0.5	
Fe <sub>2</sub> O <sub>3</sub> /CaO	<0.3~3<	
S/coal	<2 %	
<u>Fouling</u>		
	basic content; Na <sub>2</sub> O, K <sub>2</sub> O, Cl, CaO, S	fouling on inner furnace, radiation heating surface
<u>Wear-out Nature</u>		
	quart, Fe <sub>2</sub> O <sub>3</sub> , S	wear of mill, coal tube, heat transfer surface

Grindability: Pulverized coal firing is generally characterized by combustion state after

crushing it into fine particles of 50 to 100  $\mu\text{m}$ , drying them, and burning them. The important point in the firing is to ensure the complete burning within a combustion chamber. In case of off-specification, non-burn loss increases. Much moisture content of 20% or more leads to decline of the mill capacity.

**Slagging:** coal slagging is a phenomenon, which stems from the melting of coal ash within a boiler furnace, adheres to the radiation heating face of the mill, hardens and accumulates there when it is cooled. Ash melting temperature is judged based on whether the ash melting temperature is higher or lower than the gas temperature near the radiation heating face. Ash higher alkaline ratio means that low-fusing-point oxides and compound salts are liable to be produced, and that the slagging characteristic is considered. If the ratio of  $\text{Fe}_2\text{O}_3/\text{CaO}$  in ash is between 0.3 and 3, there is a tendency toward the productions of compounds with a low fusing point. The sulphur produces low-fusing-point complex salt, accelerating the generation of fouling.

**Fouling** is a phenomenon in which melted ash coagulates to the inner surface of combustion chamber due to the content of  $\text{Na}_2\text{O}$ , or so on.

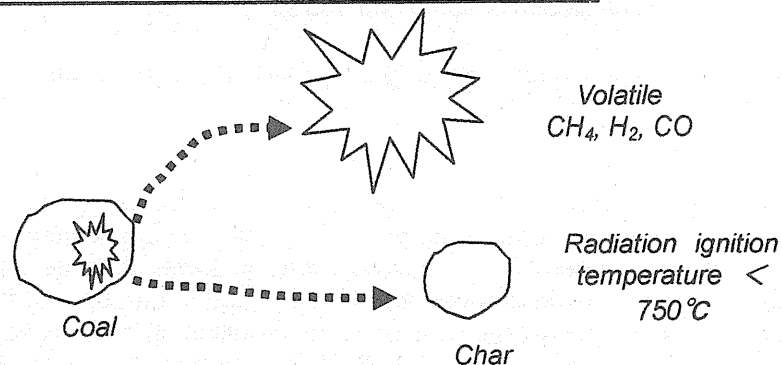
Wear-out nature, which causes abrasion to a mill, tube, heat transfer face, etc., is judged based on analysis values such as quart, so on.

For the detail information, refer to the pages at P107~110 or E.49~54.

### 3-1-2 Coal combustion

In suspended combustion in the form of pulverized coal, its ignition time and combustion time are extremely shortened, and its burner combustion becomes possible, as if it were heavy oil or gas fuel. In pulverized coal combustion, the primary combustion range is chiefly the combustion range of volatile content such as  $\text{CH}_4$ ,  $\text{H}_2$  and  $\text{CO}$ . The second combustion range is primarily the combustion range of char. The speed of combustion of char is extremely slow, compared with that of volatile matter. Accordingly the combustion time of char accounts for about 80 to 90% of total combustion time. Using a normal pulverized coal combustion boiler, a radiation ignition temperature of  $750^\circ\text{C}$  or less is empirically known as causing virtually no combustion-related problems.

#### Combustion Mechanism of Pulverized Coal



To complete combustion of fuel, more surplus air than theoretical air volume ( air ratio of 1.2 to 1.25 for high volatile content bituminous coal) is necessary. Therefore, various methods have been employed to reduce the  $\text{NO}_x$  as shown in a slide. Among these methods, combustion control itemized No. 1 to 4 in a slide is possible by means of changing operation method.

1. Reduction of surplus air ratio (high volatile coal; 1.2~1.25)
2. Lowering combustion air temp. (normally 250~350 °C)
3. Two stage combustion (1st burner + 2nd burner)
4. Recycling exhaust gas (<20~30%)

The inner-furnace denitrification method is to reduce, in combustion chamber, NO which was generated in the same combustion chamber, by means of hydrocarbon. This process is composed of two stages. To validate this process, at first stage, (1) the atmospheric temperature must be higher than the hydrocarbon decomposition temperature (about 900°C), (2) oxygen must be present, (3) the volume of reduction-use hydrocarbon to be used for mixture (fuel) must be more than the chemical equivalent of existing oxygen. The second stage is to arrange for the complete incineration of non-combustion portions. For this, (1) the atmospheric temperature must be higher than the reaction temperature of the non-burned portions, (2) the sufficient volume of oxygen for the complete incineration of the non-burned portions must be supplied.

#### 5. Inner-furnace denitrification

##### *1st Process*

- furnace >900°C HC decomposition
- O<sub>2</sub> existing
- reductant HC > chemical equivalent O<sub>2</sub>

##### *2nd Process*

- atmosphere temp. > reaction temp. of non-burned portion
- sufficient O<sub>2</sub>

NO<sub>x</sub> curtailment methods based on the improvement of the burner structure can broadly be grouped into the three shown in a slide.

#### *6. Low NO<sub>x</sub> burner*

- slow mixture air & fuel
- promotion of unevenness comb.
- acceleration of flame heat radiation

For the detail information, refer to the pages at P.110~112 or E.54~58.

### **3-2-1 Oil Combustion**

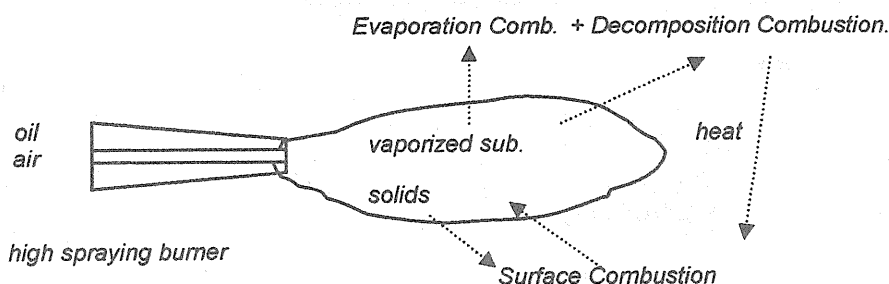
Combustion mechanism of fuel oil can be divided into combustion of evaporated substances and combustion of decomposed substances. Fuel oil is a complicated multiple hydrocarbons. The decomposing temperature of hydrocarbons is lower than its ignition or combustion temperature, and then hydrocarbons are decomposed to carbon and flammable gas before its combustion, which combine with oxygen, resulting in combustion. Carbon becomes carbon dioxide gas, as a result of surface combustion, while flammable gas and hydrocarbon oxidized, turning into carbon dioxide gas and water through diffusion combustion. The heat resulting from this combustion further leads to thermal decomposition. Because combustion by decomposition and surface combustion occur alternately or simultaneously, combustion reaction progresses continually.

Combustion reaction is affected by oil jet speed (combustion reaction  $\propto$  oil jet speed) and



combustion speed (combustion reaction  $\propto$  combustion speed), which are influenced by the contact surface area between fuel and air. The burner with high spraying performance is important to complete combustion.

### Oil Combustion Mechanism



Oil properties of JIS C-Heavy Oil as an example are shown in a table. Oil properties effect on exhaust gas composition as shown in a slide. If residual carbon content is much, it is liable to turn into residual carbon-type soot and dust, and carbon is liable to attach to the burner tip, should the combustion condition deteriorate. Fuel oil contains ash content. The ash content includes sodium (Na), potassium (K), iron (Fe), silicon (Si), vanadium (V), aluminum (Al), and nickel (Ni). These are adsorbed by combustion gas, cause melting and chemical change and attach to and accumulate on gas paths, causing the growth of pressure loss, blocking of heat transfer, mechanical wear and chemical corrosion.

### Effect of Fuel Oil Properties on Exhaust Gas Composition

Subs.	Con.wt. %	Pollutants	Damages
N	0.01~0.6	NO <sub>x</sub>	Air pollution
S	0.2~3.0※	SO <sub>2</sub> , SO <sub>3</sub> → SO <sub>4</sub> (SO <sub>x</sub> )	Air pollution, corrosion clogging
Red. C	4.0~11.5※	Dust	Dust, carbon adhere
Ash (Na, K, V, ---)	< 0.02※	Adherents	Scaling, Vanadium attack, corrosion, mechanical wear, etc.

※: JIS C-Heavy Oil

For the detail information, refer to the pages at P.81, 112~115 or E.58~62.

### **3-2-2 Oil - NO<sub>x</sub> Generation**

In case of fuel oil combustion, burning is continued due to the evaporation and ignition of oil sprays near a burner. In line with the generation of fuel NO<sub>x</sub> due to oxidation of nitrogen

oxides within fuel oil, high-temperature flames are formed, and the ratio of thermal NOx generation becomes high. However, because the volume of nitrogen compounds in fuel oil is smaller than in coal, the overall NOx emission volume is smaller than that during coal combustion.

NOx Generation and its Control in Oil Combustion

Generation

*Thermal NOx (N in Air)*  
*Flame temp.*  
*O2 concentration*  
*Retention time*

*Fuel NOx (N in Fuel)*  
*O2 concentration*  
*Nitrogen in fuel*

Because NOx generation forms are different, based on the kind of fuel, it is necessary to take NOx control measures suitable for individual fuels. In case of oil-firing boilers, NOx control measures such as (1) 2-stage combustion, (2) exhaust gas recycling, (3) the use of low NOx burner and (4) expansion of furnace size (proportion of heat radiation through flames), are adopted.

Control Measures

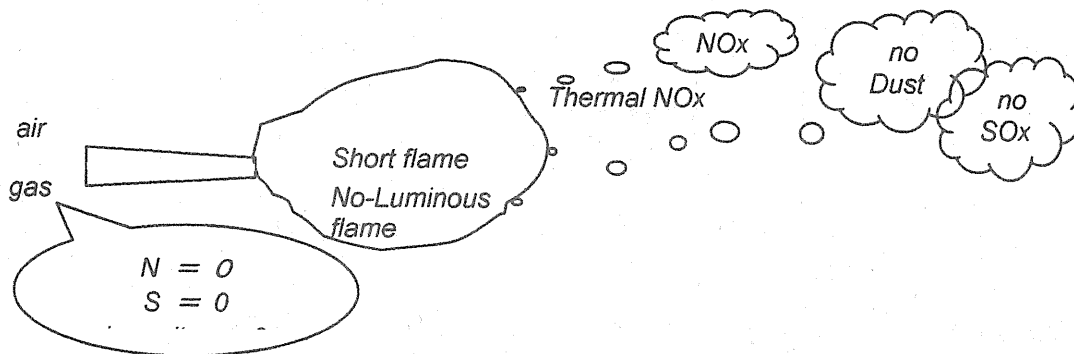
- 2-stage combustion
- Exhaust gas recycling
- Low NOx burner
- Furnace size expansion

For the detail information, refer to the pages at P.116 or E.62~63.

**3-3 Gas**

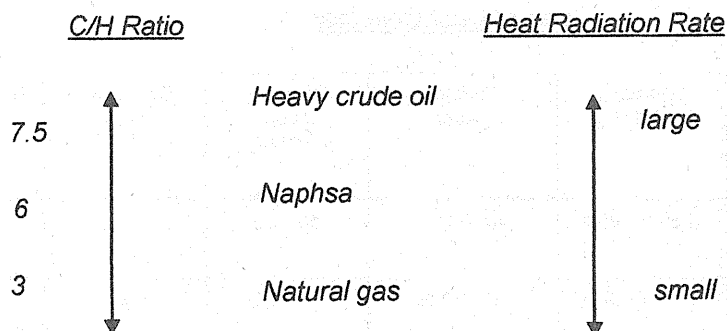
Compared with heavy oil combustion, the combustion of natural gas has the following characteristics;

Gas Combustion Mechanism



The combustion is affected through the diffusion (mixing) combustion with air, based on low-pressure fuel jetting. Because there is no spraying/evaporation process seen in heavy oil combustion, flame is short.

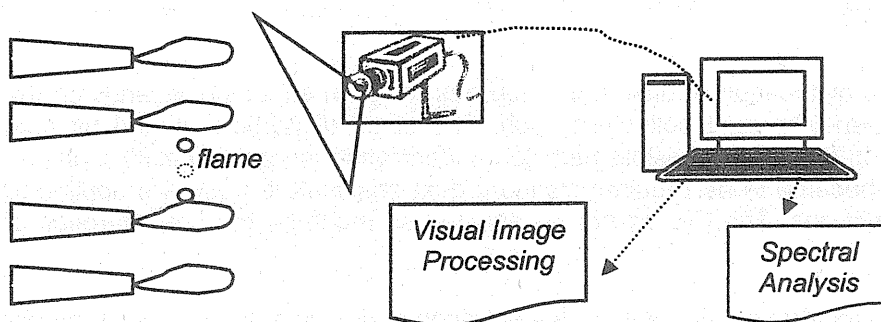
Because C/H of gas is small, no soot is generated in the process of combustion, and generally no-luminous flames are generated in the course of its combustion. Because there is no N content, S content or impurities within the fuel, the staining, wear or corrosion is little, therefore SO<sub>x</sub> and dust are not discharged.



Although this clean fuel relatively frees from the generation of air pollutants, attention is necessary because if burner design or the handling of fuel is mistaken, oscillation combustion or explosion may occur.

#### Control of NO<sub>x</sub> Generation + Oscillating Combustion Preventive Measures

It is generally known that the heat radiation ratio of flames decreases as the ratio of the carbon content to the hydrogen content (C/H) within fuel becomes smaller. C/H is 3 for normal gas, 6 for naphtha, and about 7.5 for heavy oil.



During low NO<sub>x</sub> operation, unburned portions tend to grow, or flames are liable to fill the furnace, affecting the boiler performance. As such, operation control including combustion adjustment is important. Because a thermal power generation-use boiler is equipped with many burners, it is important to adjust the air volume by means of air allocation dampers, etc. to make air ratios of individual burners as even as possible, to curb NO<sub>x</sub> by preserving the generation of unburned matter and to equalize the length of flames.

For the close combustion adjustment of individual burners, it has become difficult to operate the boiler in an appropriate manner simply through combustion adjustment, based on experience and hunch, as well as on conventional measuring gauges. The individual combustion diagnostic method, based on optoelectronics technology, has recently been developed and put into actual use.

For the detail information, refer to the pages at P.116~118 or E.63~66.

## 4. Dust Collector

### 4-1 Types of Dust Collectors

When we select the dust collectors, physical properties of particles and gases as shown in the slide should be taken into consideration;

Type of Dust Collector

Type	Applic. Particle ( $\mu\text{m}$ )	Operating ( $^{\circ}\text{C}$ )	Cutback Level	Pressure Drop ( $\text{mm H}_2\text{O}$ )	Equipment Cost	Running Cost
Gravity	$\geq 50$	d.p. $\sim 400$	40~60 %	10~15	S	S
Inertia	$\geq 10$	d.p. $\sim 400$	50~70 %	30~70	S	S
Centrifuge	$\geq 3$	d.p. $\sim 400$	10 $\text{mg}/\text{m}^3$	50~150	M	M
Scrubbing	$\sim 0.1$	no-limit	$\neq 20 \text{ mg}/\text{m}^3$	300~800	M	L
Filtration	$\sim 0.1$	no-limit	5 $\text{mg}/\text{m}^3$ or less	100~200	M	M
EP	$\sim 0.03$	d.p. $\sim 400$	5 $\text{mg}/\text{m}^3$ or less	10~20	L	S

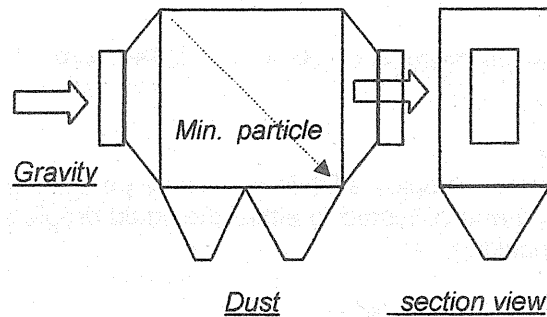
The sizes and particle distribution of dust in the flue gas have an effect significantly on the particle removal efficiency in dust collectors each. The sizes of particle abated by dust collectors are shown in the table. Invisible particle concentration is said to be 20  $\text{mg}/\text{Nm}^3$ . Filter dust collectors become to be required frequent dust shakings if these are applied to high concentration dust gas. The EP will not be affected so much by the concentration of dust in flue gas.

Regarding the dust concentration, the higher concentration of dust in a gas brings the higher removal efficiency of particle removal for the gravity collector and inertial force dust collector due to the acceleration of collision between large size particles and of coagulation of fine particles. In venturi scrubber and jet scrubber, as the higher concentration of dust causes the wear at the throat part of venturi, these should be applied the gases of dust concentration 10  $\text{g}/\text{Nm}^3$  or less.

For the detail information, refer to the pages at P.168~169 or 185, E. 140~143, 172.

### 4-2 Gravitational, Inertial & Centrifugal Dust Collector

Because of the density difference between solids and gases, in laminar flow their stream lines are different if the direction of flow is changed. This fact is frequently exploited to separate solid particles from a gas stream, usually by suddenly changing the direction of flow of the gas stream.



In gravity dust collector, a settling chamber reduces the velocity (normally 1~2 m/second) of the gas stream so that the particles drop out by gravity. It is a large device not often used as a final control mechanism. If it is assumed that Stokes' s law applies, then the particle size which will be removed with 100% efficiency is given by the equation.

Stokes' Law

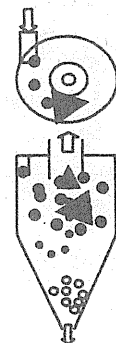
$$V = \frac{g}{18\mu} (\rho_1 - \rho) D^2 \quad (\text{cm/s})$$

$V$ : settling velocity (cm/sec)  
 $g$ : gravitational acceleration (cm/s<sup>2</sup>)  
 $\mu$ : gas viscosity (kg/ms)  
 $\rho_1$ : particle density (g/cm<sup>3</sup>)  
 $\rho$ : gas density (g/cm<sup>3</sup>)  
 $D$ : particle diameter (cm)

In the centrifugal force collector generally called cyclone dust separator, the centrifugal force exerted on a particle in a cyclone is given by the equation. For a large volume of gas treatment, small cyclones are connected in parallel and used as multi-cyclone. The inlet-gas velocity is set at 10 ~25 m/s.

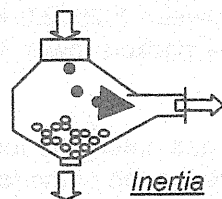
$$\text{Centrifugal force } (F) = mv^2 / R \quad (\text{N})$$

$m$ : particle mass (kg)  
 $v$ : particle velocity (m/s)  
 $R$ : cyclone radius (m)



Inertia

In an inertial dust collector, the gas stream is forced to collide with an obstacle or the gas flow direction is sharply changed to separate and collect dust particles in gas by using inertial force.



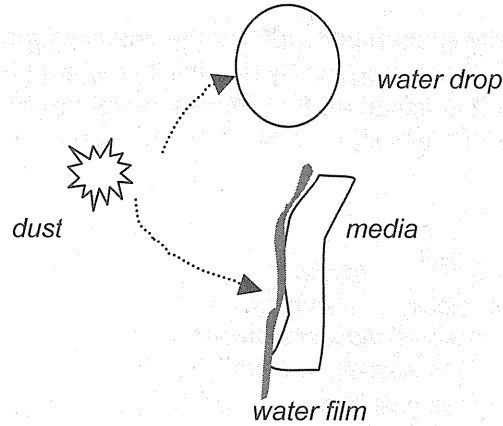
Inertia

For the detail information, refer to the pages at P.170~171 or E.144~146.

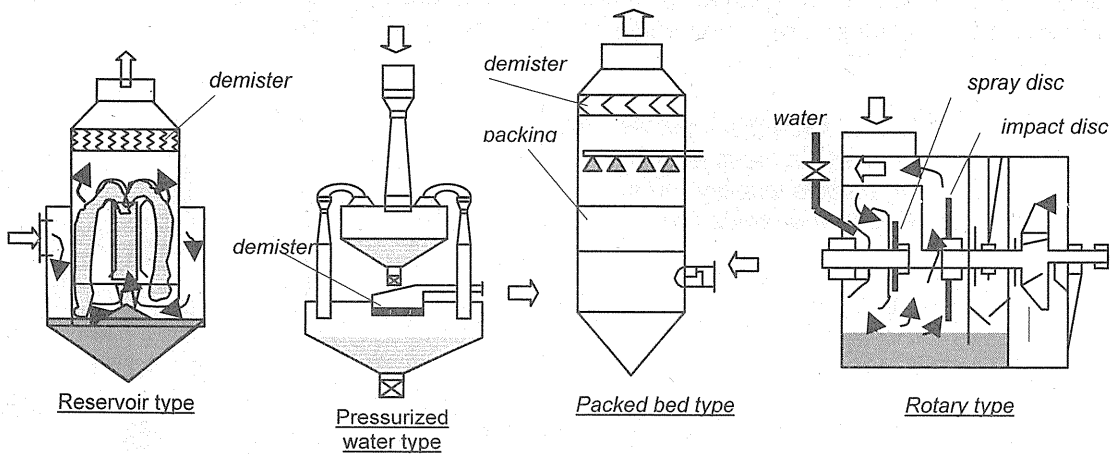
### 4-3 Scrubbing Dust Collector

Scrubbers, known as wet collectors, employ a liquid to remove particles from a gas stream. In use, the particles are adhered and collected to either the liquid droplets or liquid film that is poured continuously on the packing.

Principle of dust collection:



Various scrubbing dust collector systems have been developed, and can be roughly divided into reservoir type, pressurized water type, packed bed type and rotary type as shown in a slide.



The use of packing allows a smaller tower to be used but the pressure drop is higher (thereby increasing efficiency). The pressure drop through a spray tower is typically between 0.25~0.5 kPa. For the packed bed it is between 0.25~2.0 kPa. The liquid to gas ratio in a spray tower is typically 1.3~2.7 l/m<sup>3</sup>. In a packed tower it is normally between 0.1~0.5 l/m<sup>3</sup>.

In the packed bed type, basically, the contaminated gas enters the tower at a low level and rises due to its buoyancy. The scrubbing liquid enters the top of the tower and sprays down on top of the vertically rising dirty gas. At interception the contaminants adsorb to the falling

liquid and the purified gas continues to rise and emits from the top the tower. Packing (e.g. random plastic piece) improve the adsorption efficiency. The nozzles on the spray arms atomize the liquid.

To achieve efficient performance of scrubbing dust collector, it is important to select a gas flow velocity and liquid to gas ratio suitable for the system.

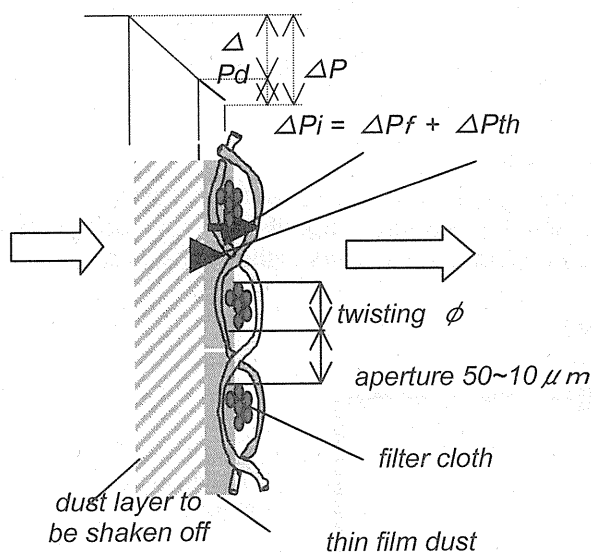
For the detail information, refer to the pages at P.171 or E.147.

#### 4-4 Filter Type Dust Separator

Principal types of filter type dust collectors are (1) the bag filter (2) the cartridge filter. The design of both is quite similar. However the bag filter is the more commonly used.

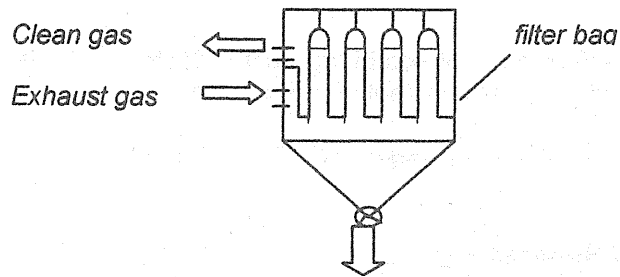
When gas contained dusts of certain particle sizes is passed through a filter cloth as shown in a slide, they adhere to the filter cloth, and bridges are formed between the strands of cloth. The primary adhesion layer has many fine pores, and these fine pores collect the fine dust particles.

#### Filtration Mechanism



Various woven fabrics made from natural fiber, synthetic fiber and glass fiber, and non-woven fabrics made from similar materials are used for filter cloth. In the operation of the bag filter type dust collector, prevention of blockage of the filter surface is important. When the pressure loss of the bag filter has reached its regulated value, it is necessary to shake dust off of the bag filter. There are 2 kind of shake-off methods, the intermittent method and continuous method. In the intermittent method, the dust collecting chamber is partitioned into 3~4 chamber. The dampers installed on both the inlet and outlet of filter is closed and then the dust adhering to the filter cloth is shaken off. In the continuous method, the dust adhering to the filter cloth is constantly shaken off under continuous filtration. Therefore, the pressure loss will remain roughly at a fixed level, making this method suitable for the treatment of gases containing high concentrations of dust and soot and of gases containing adhesive dust and soot.

Typical bag filter unit



The apparent filtration rate (raw gas volume per effective area of filter cloth) should usually fall in the range of 0.3~10 cm /s.

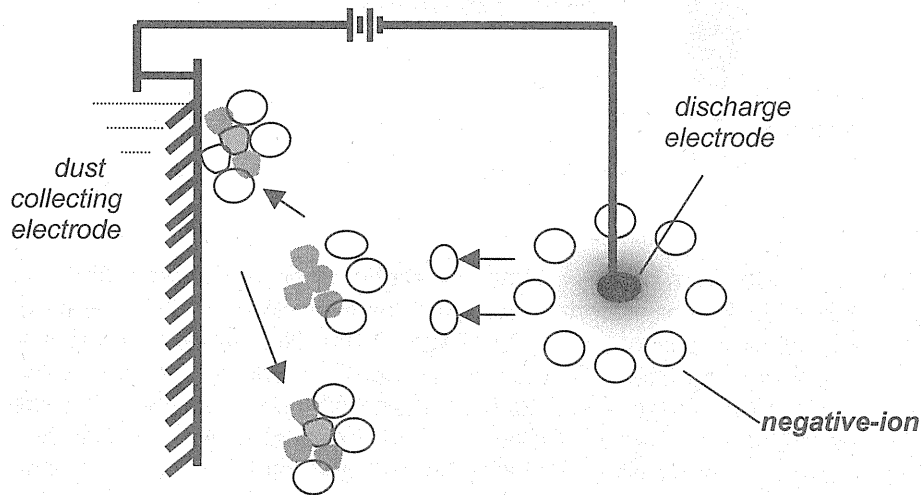
<u>Type:</u>	<u>Filter cloth:</u>	<u>Dust shake-off:</u>	<u>Apparent filtration rate:</u>
(1) bag filter	(1) woven fabric	(1) intermittent	0.3~10cm/s
(2) cartridge filter	(2) nonwoven fabric	(2) continuous	

For the detail information, refer to the pages at P.171~172 or E.147~148.

**4-5-1 Electrostatic Precipitator (EP)**

An EP collects dust particles in flue gas by using corona discharge to give them an electrical charge. The EP is not much affected by the properties of gas and dust, can do highly efficient dust collection, and can collect fine particles without pressure loss.

Principle of dust collection



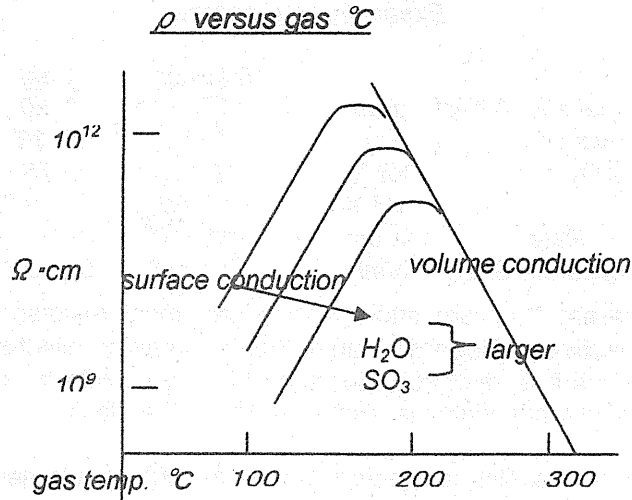
A conductor discharge electrode is used as the negative electrode, and a dust collecting electrode is used as the positive electrode as shown in a slide; high voltage direct current electric power is used for charging. When the strength of the electric field is increased, the gas around the electrode is partially broken down, corona discharge occurs, and a negative corona and many negative ions are generated. Negative ions and free electrons move to the



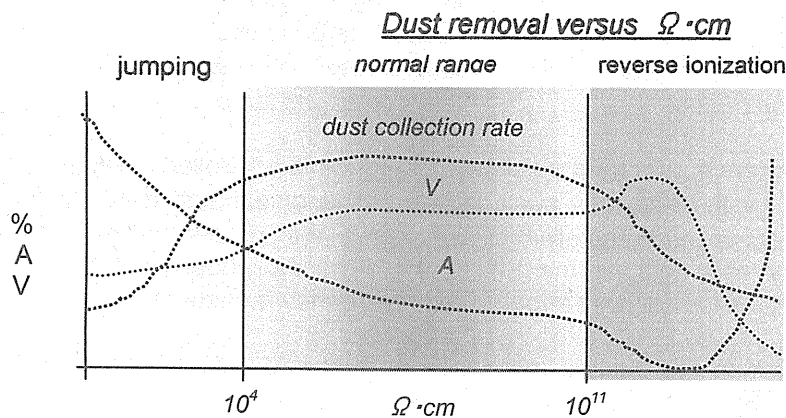


#### 4-5-2 Factors working on Electrostatic Precipitator

The left side figure shows the relationship between the gas temperature and the electric resistance of dust, which generally shows its highest value at the range between 120 and 180°C. This comes from the differences between the way of electric current flows through dust particles in the low temperature range and in the high temperature range. Moisture content and SO<sub>3</sub> in exhaust gas adhere to dust particles in the low temperature range, so electric current can easily flow along the surface of dust particles. On the other hand, in the high temperature range, electric current flow through the inside of dust particles becomes dominant. This is affected by the quantity of alkaline metals (Na, K) in the dust.



A right side slide shows the relationships between the electric resistance of dust and dust collecting performance, the characteristics of charged voltage and current in an EP. In the range of  $10^4$   $\Omega\text{-cm}$  or less (jumping range), when electrically charged dust adheres to the dust collecting electrode, dust immediately loses its negative electric charge, so dust collecting efficiency decreases. In the range between  $10^4$  and  $10^{11}$   $\Omega\text{-cm}$ , ideal dust collection is done. Dust with electric resistance of over  $10^{11}$   $\Omega\text{-cm}$  (reverse ionization range), electrical neutralization of the negatively-charged dust adhered to the dust collecting electrode becomes slow. Therefore, electric charges accumulate on the surface of the dust, and the strength of electric field inside the dust layer become high, and it causes dielectric breakdown inside the dust layer, and the dust collection efficiency will remarkably decrease.



The disadvantages and disadvantages of an EP are shown in the table.

Advantages and disadvantages of EP

Advantages  
large gas volume  
fine particles of submicron  
high temperature gas  
wet type dust collection  
suitable operation  
inexpensive maintenance

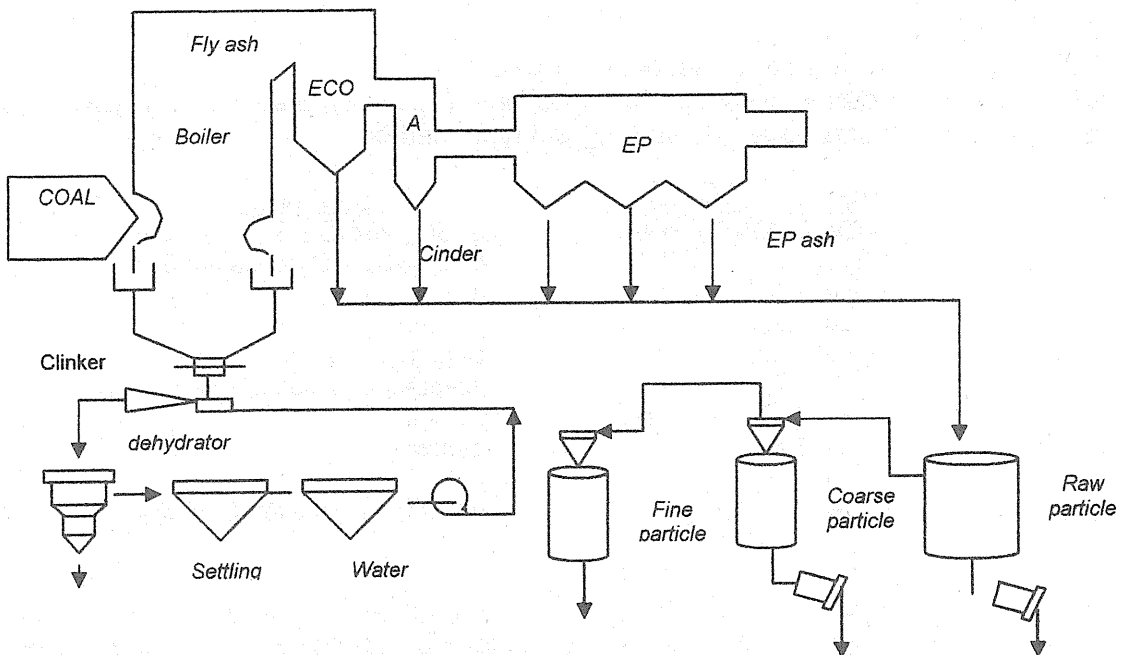
Disadvantages  
initial cost – expensive  
affection of apparent  $\rho$  ( $\Omega$ -Cm)  
system size- large  
high level accuracy in manufacturing

For the detail information, refer to the pages at P.176~179 or E.155~161.

**4-6 Ash Treatment**

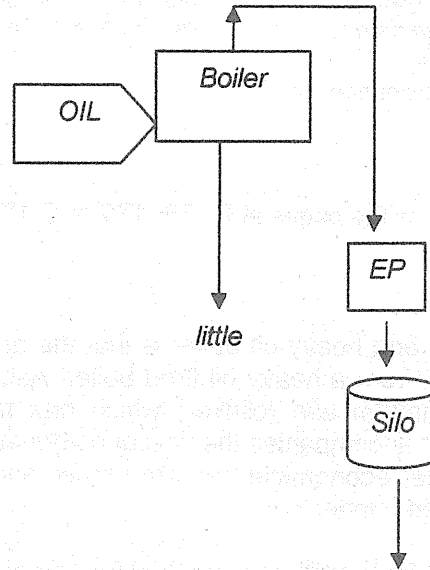
One difference between coal and heavy oil boiler is that the ash volume generated in coal fire boiler is greater than that from a heavy oil fired boiler. Ash discharged from a boiler is roughly classified into the bottom ash (clinker) which has fallen down underneath the furnace, and the fly ash which accompanies the flow of combustion gas, then falls down and collected or stored in the fuel economizer, air pre-heater and EP (ash discharged from former two are generally called "cinder").

Coal ash is effectively utilized for landfill, raw material for cement, fly ash cement, aggregate, civil engineering, architectural material, fishery and agriculture industries , desulphurizing agent, etc.



In case of oil fired boiler, the volume of ash collected and discharged is less than that from a

coal fired boiler, and the properties of ash are roughly fixed in accordance with the variety of heavy oil. Also, almost all the ash is collected by the EP. Therefore, the structure of the ash disposal equipment is relatively simple, and ash is transferred from each hopper of EP to the storage silo using the pressure transfer or vacuum transfer method. Ash discharged from oil fired power station contains unburned combustibles and heavy metals, so that almost of this ash is effectively utilized as an alternative fuel for cement manufacturing or as the raw material for the recovery of valuable materials.



For the detail information, refer to the pages at P.179~184 or E.161~170.

## 5. Flue Gas Desulphurization

### 5-1 Flue Gas Desulphurization Methods (FGD)

Flue gas desulphurization systems are divided into (1) wet type and (2) dry type; most power generation plants have adopted the wet type method.

<u>Method</u>	<u>Absorbent/ Adsorbent</u>	<u>Byproducts</u>
Wet type	NaOH or Na <sub>2</sub> SO <sub>3</sub> solution	Na <sub>2</sub> SO <sub>3</sub> , NaNO <sub>3</sub> , SO <sub>2</sub> , gypsum
	NH <sub>3</sub> -water	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> , SO <sub>2</sub> , gypsum, S
	Slaked lime or limestone slurry	gypsum
	Mg(OH) <sub>2</sub> -slurry	SO <sub>2</sub> , gypsum (blended with slaked lime slurry)
Dry type	Basic Al <sub>2</sub> (SO <sub>4</sub> ) <sub>3</sub> -solution	gypsum
	Dilute-H <sub>2</sub> SO <sub>4</sub>	gypsum
	Activated carbon	(NH <sub>4</sub> ) <sub>2</sub> SO <sub>4</sub> , gypsum, S, H <sub>2</sub> SO <sub>4</sub>

The wet type has become the main stream flue gas desulphurization method. The absorbent for the wet type method, a solution or slurry containing a compound such as a sodium, calcium or magnesium compound which reacts with SO<sub>2</sub> is used. The wet type method is often classified according to the variety of absorbent as shown in a slide. At present, the method called the "lime and gypsum method", using limestone slurry as

the absorbent and recovering gypsum, has been adopted in most power generation plants in Japan because limestone is relatively cheap, the economy of the construction cost and operation cost of the wet type flue gas desulphurization system is good, the stability and safety of system operation are excellent, and gypsum can be sold steadily.

- limestone ⇒ cheap
  - initial & operating cost ⇒ economics
  - system ⇒ stability & safety
  - gypsum ⇒ stable sales
- } reasons of most popularly used

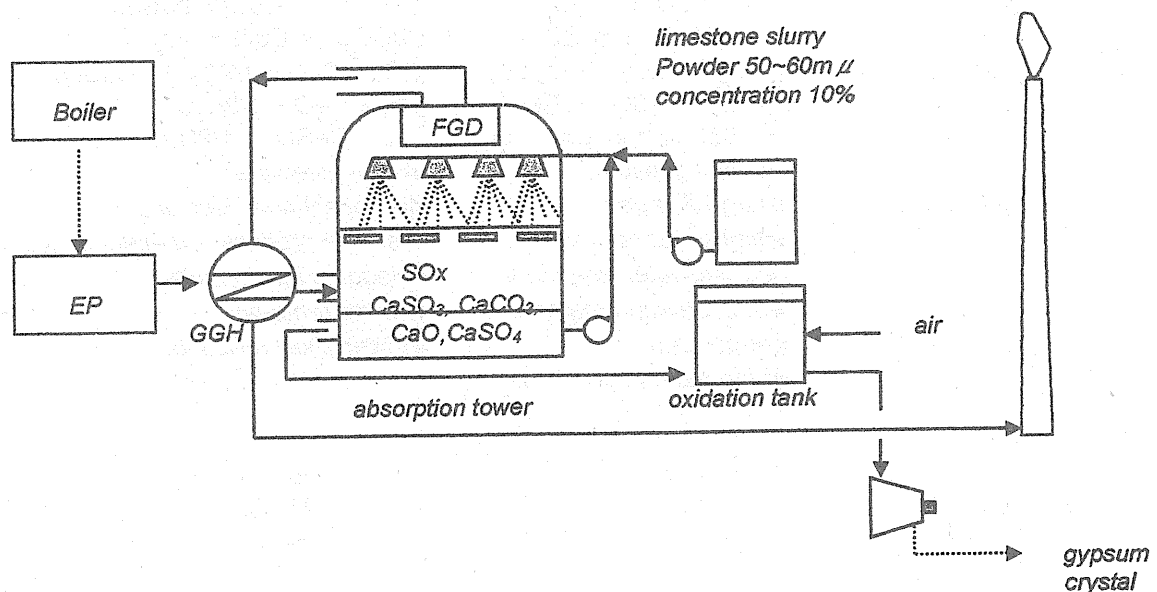
In contrast, the dry type has problems with the safety and deterioration of the absorbent itself, worsening of recycling and recovery rates, generation of effluent, and clogging of equipment accompanying the handling of dry dust, as well as reasons related to the difficulties of maintaining safety, the storage and sales of by-products, and consideration of the safety of long-term continuous operation.

For the detail information, refer to the pages at P.186 or E.175

### 5-2 Wet Type Lime & Gypsum Method FGD System

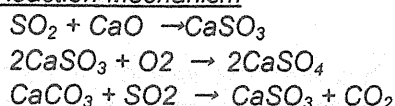
Flue gas from the boiler is led to the electrostatic precipitator (EP) to remove soot and dust. Poor performance by the dust collector causes clogging of the gas-gas heater (GGH) and increased leakage of soot and dust, etc. When a large amount of soot and dust collected by the flue gas desulphurization (FGD) system, this causes various mechanical problems and lowers the quality of gypsum, and/or decreases the activity of the absorbent; therefore, it is desirable to install a dust collector which has the highest possible performance.

The GGH is constituted from the recovery side which recovers heat from the gas at the outlet of the dust collector, and the reheating side which increases the gas temperature at the stack inlet by providing the recovered heat.



In the absorption tower, a slurry-like absorption liquid containing limestone powder with particle sizes of around 50~60 microns is circulated in the absorption tower, and when this liquid and flue gas have come into efficient contact, SO<sub>2</sub> in the gas is taken into the liquid and removed. Sulfur dioxide (SO<sub>2</sub>) combines with lime (CaO) and changes to calcium sulfite (CaSO<sub>3</sub>). Part of CaSO<sub>3</sub> is naturally oxidized by the oxygen in the flue gas inside the absorption tower, and becomes gypsum (CaSO<sub>4</sub>), but the rest of the CaSO<sub>3</sub> is forcibly oxidized by the air in the oxidation tank.

Reaction Mechanism



Gypsum slurry is dehydrated using a dehydrator and taken out as gypsum crystal with a moisture content of 10% or less.

For the detail information, refer to the pages at P.190~192 or E.181~184.

**5-3 Simplified FGD System**

The wet type lime and gypsum method flue gas desulphurization system consists of three stages of absorption reaction, oxidation reaction, and neutralization reaction as shown in equations from the top in order in a table. This system has the distinctive features previously mentioned, but is expensive to construct. Therefore, the simplified flue gas desulphurization system has been developed and adopted in developing countries.

Comparison of Simplified FGD with Conventional FGD

	<i>Lime &amp; Gypsum Method</i>	<i>Simplified FGD Semi-dry Method Intrafurnace Desulphurization + Water Spray Method</i>
<i>Alkali</i>	<i>CaCO<sub>3</sub> powder</i>	<i>CaCO<sub>3</sub> powder</i>
<i>Reaction</i>	<i>SO<sub>2</sub> + H<sub>2</sub>O → H<sub>2</sub>SO<sub>4</sub> H<sub>2</sub>SO<sub>3</sub> + 1/2O<sub>2</sub> → H<sub>2</sub>SO<sub>4</sub> CaCO<sub>3</sub> + H<sub>2</sub>SO<sub>4</sub> + H<sub>2</sub>O → CaSO<sub>4</sub> + 2H<sub>2</sub>O + CO<sub>2</sub></i>	<i>CaCO<sub>3</sub> → CaO + CO<sub>2</sub> SO<sub>2</sub> + CaO + 1/2O<sub>2</sub> → CaSO<sub>4</sub> SO<sub>2</sub> + CaO + 1/2H<sub>2</sub>O → CaSO<sub>3</sub> + 1/2H<sub>2</sub>O</i>
<i>Advantages</i>	<i>★useful gypsum ★large flue gas ★high-level removal ★wastewater treatment</i>	<i>★no wastewater ★compact size, less space ★simple process, excellent in economics</i>
<i>Disadvantages</i>	<i>★anticorrosion material ★large area ★high maintenance cost</i>	<i>★slagging inside boiler ★lower removal ★lower alkali utilization</i>
<i>Cost</i>		
<i>Equipment</i>	<i>100</i>	<i>20~30</i>
<i>Operation</i>	<i>100</i>	<i>75~80</i>

In simplified FGD, the lime stone powder (CaO) and water are directly injected into the furnace. In a furnace, desulphurization reactions are divided into first FGD of first two

equations and 2nd FGD of third equation as shown in a table. The advantages and disadvantages of both methods are summarized in a table by comparison.

The cost reduction of simplified flue gas desulphurization (FGD) system was achieved on the basis of general procedures for curtailing of the construction cost of the system; (1) curtailing of engineering time, (2) making the equipment and machines constituting the system compact, (3) studying the material qualities for equipment and machines, (4) simplification of process, and (5) simplification of equipment, machinery and facility used for the process, by simplification of control method, but care taken by the user's side is also very important.

For the detail information, refer to the pages at P.188~189 or E.178~179.

## 6. Flue Gas Denitrification

### 6-1 NOx Abatement Method

The term of NOx implied two major oxides, nitrogen oxide (NO) and nitrogen dioxide (NO<sub>2</sub>). In Combustion, NO is the dominant of the two, NO<sub>2</sub> mainly a downstream derivative of NO. There are two main mechanisms of NOx production from combustion process; (1) from the reaction of N<sub>2</sub> in the air with oxygen at the high temperature of the burner chamber, known as thermal NOx, (2) from the nitrogen existing in the fuel with oxygen at high temperature, known as fuel NOx.

Typical efficiencies and the applicability of the various methods of NOx reduction are shown in a table at the top of the slide (quoted from Environmental Engineering, P.777, McGraw-Hill, 1998). Three methods from the top depend on the adoption of innovative design to reduce NOx generation, and latter two are processes selectively used in the industry to remove generated NOx. Recirculation of flue gas acts by reducing the peak flame temperature and the quantity of oxygen present to minimizing NOx formation. In low NOx burner, the burner designed to fire fuel at low excess air. Staged combustion can be used to reduce the peak temperature. Up to three stages can be used, but this requires very tight control over both the fuel and air flow rates to each stage.

Reduction of NOx Generation & Denitrification Methods

Method	Applicability	NOx red. (%)
Flue gas recirculation	T-NOx	70~80
Low NOx burner	F-NOx, T-NOx	10~25
Staged burners	F-NOx, T-NOx	40~70
SCR	F-NOx, T-NOx	80~90
SNCR	F-NOx, T-NOx	60~80

Remarks; T-NOx: Thermal NOx, F-NOx: Fuel NOx

In a lower table, major flue gas denitrification processes are shown. SCR is a simple process for decomposing NOx into N<sub>2</sub> and H<sub>2</sub>O, by passing the flue gas with ammonia (NH<sub>3</sub>) in the flue gas, through the catalyst layer. This process is suitable for treating large volumes of exhaust gas. SNCR does denitrification without using a catalyst, by injecting ammonia in the high temperature range of about 800~1,000°C. The denitrification rate of this process is low compared to SCR. NSCR does the catalytic reduction of NOx using a noble metal such as platinum (Pt) as the catalyst and CH<sub>4</sub>, CO or H<sub>2</sub> as the reducing agent. This process is hard to apply for a large volume of boiler exhaust gas with low concentration of NOx.

Catalytic cracking process, using noble metal at about 450°C, and other processes such as absorption process and adsorption process, has not reached the level of practical use. Wet process are complicated and have a problem of wastewater treatment, so no actual system has been adopted by normal power generation plant.

### Denitrification Process

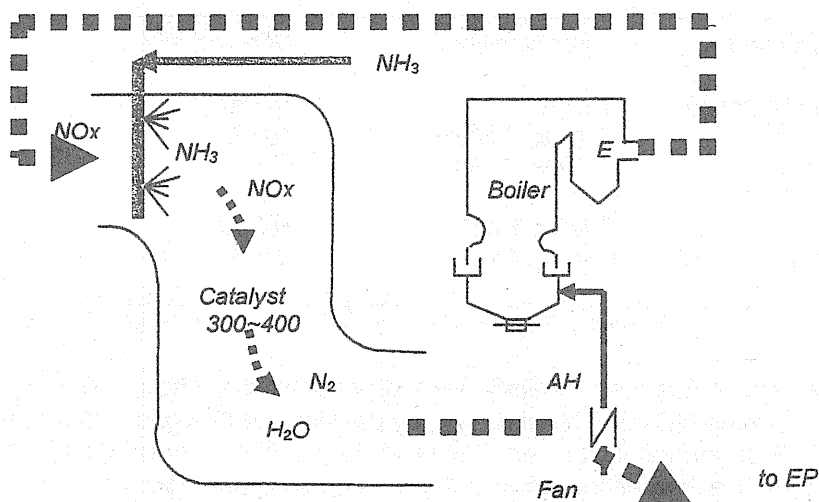
<u>Process</u>	<u>Method</u>
<u>Dry Process</u>	
SCR (Selective catalytic reduction)	NH <sub>3</sub> , catalyst
SNCR (Selective non-catalytic reduction)	NH <sub>3</sub> , Gas temp. 800~ 1,000 °C
NSCR (Non-selective catalytic reduction)	catalyst (Pt) + CH <sub>4</sub> , or CO, or H <sub>2</sub>
Catalytic cracking	catalyst (Pt, ...)
<u>Wet Process</u>	
	NOx + SOx removal
	Complicate process
	wastewater treatment

For the detail information, refer to the pages at P.200~201 or E.196~197.

### 6-2 NH<sub>3</sub> Catalytic Reduction Process

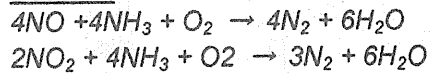
In this process, after ammonia (NH<sub>3</sub>) is injected into the flue gas, and this admixture is passed through the catalyst layer, NO<sub>x</sub> decomposes into N<sub>2</sub> and H<sub>2</sub>O as shown in a slide. Ammonia gasified in the carburetor goes through the accumulator and is diluted by some of the air provided by the forced draft fan for boiler, then injected into the exhaust gas from the ammonia injection nozzle. The optimum temperature range for these reactions is 300 ~400°C, equivalent to the gas temperature at the outlet of the boiler economizer (EC). Followings are the features of this process; (1) simple process, easy operation, few troubles and highly reliability, (2) no-wastewater generation and no need of reheating of exhaust gas, (3) high rate of denitrification, (4) no by-product.

SCR Process : Ammonia Catalytic Reduction Process





Reaction



Catalyst

support: ceramic (Ti, Al, ...)  
 catalyst: metals  
 shape: granule, grid-form  
           honeycomb, plate  
 control: denirification rate  
           catalyst bed draft loss

Several kinds of catalysts are in practical use. These mainly use porous ceramic such as titanium or aluminum ceramic as the support, and any of several kinds of metal oxides which are the active components of the catalyst are held by this support in form of granulated, grid-form, honeycomb, or plate. The control of catalyst is done by investigation of changes in the catalyst with elapsed time, record the denirification rate and operation data including catalyst bed draft loss under the fixed condition.

For the detail information, refer to the pages at P.202~206 or E.199~206.

**7. Stack**

The objectives for the stack of thermal power generation plant are to lead the exhaust gas generated from the combustion of fuel in the boiler up to the height at which the exhaust gas does not influence the equipment or animals and plants in the surrounding area, and also to diffuse the exhaust gas into the air.

The draft force of a stack can be calculated by subtracting the friction resistance of the flue gas passage section from the sum of the draft forces of the blower and the stack itself. The equation expressed in a slide is generally used for the calculation of relationship between draft force and stack height. Stack height can be determined from this equation. However, it is necessary to increase the stack height in consideration of the flue gas diffusion surface and the height of structures in the surrounding area.

Stack height & Draft force

$$(\gamma_a - \gamma_g)H_0 + P_{eb} \geq Vg^2/2g \cdot \gamma_g + \Sigma\Delta h > 0$$

$(\gamma_a - \gamma_g)H_0$ : theoretical draft force (kg/m<sup>2</sup>)

$\gamma_a$ : air specific weight at atmosphere temp. (kg/m<sup>3</sup>)

$\gamma_g$ : exhaust gas " "

$H_0$ : stack height from datum level (m)

$P_{eb}$ : effective blower pressure (kg/m<sup>2</sup>)

$Vg$ : exhaust gas outlet velocity (m/s)

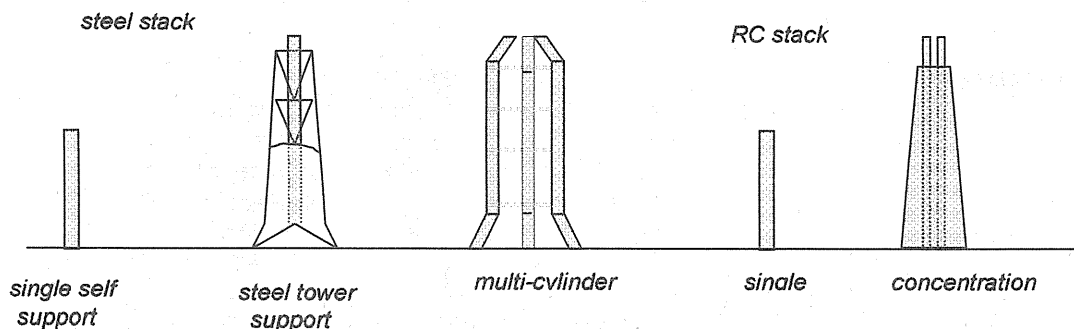
$g$ : gravitational acceleration (m/s<sup>2</sup>)

$\Sigma\Delta h$ : total pressure loss in exhaust gas route =  $\alpha \cdot V^2/2g \cdot \gamma_g$  (kg/m<sup>2</sup>)

$\alpha$ : resistance coefficient

$V$ : flue gas velocity in route (m/s)

Selection of smokestack type must involve consideration of its structural aspects and harmony of the stack with the surrounding environment in the aspect of scenic view.



The combustion exhaust gas from thermal power plant contains various corrosion products, depending on the fuel used for the boilers. Therefore, the lining must be chosen from physically and chemically stabilized materials, with consideration of the composition, temperature, and flow velocity of exhaust gas, operating conditions of the boiler and the flue gas desulphurization system.

For the detail information, refer to the pages at P.207 or E.208.

## 8. Environmental Management System

1. In EMS, trend of environmental management: Under worsening of global environmental circumstances, "sustainable development" was agreed on in the United Nations Conference on Environment and Development held in 1992. Based on this, International Organization for Standardization (ISO) has set the international standard of "environmental management / audit (ISO 14000)" in 1996. This is that a company sets a basic policy and a goal for its environmental problems based on the environmental influence caused by its business activities and the legal regulations. The company makes, executes, corrects and audits the system, rules and manuals in order to attain the goal. Such process is repeated so that the system is continuously improved. This cycle is called as PDCA cycle (Plan-Do-Check-Action). The ISO 14000 requires forming the appropriate organization, its duty and controlling system to establish and promote the pollution control.

1. Environmental Management System
  - Trend of environmental management
  - Organization for environmental management & control
  - Mission
  - Pollution control system

ISO  
14000

2. In Cooperation with local government: Cooperation with the local governments is indispensable. This includes such cooperation as installing telemeters for measured data of pollutants and taking preventive measures for emergency. The enterprises must try not only to observe pollution control laws but also to prevent pollution and protect environment positively.

2. Cooperation with Local Government
  - Cooperation in pollution control measures
  - Handling of complaints
  - Environmental protection agreement

3. Data disclosing: The enterprises must report the measurement result of emission concentration and action taken at the accident to the local governments in compliance with the law. On top these, enterprises are required to disclose these results and implementation of pollution measures publicly based on the environmental accountability.

### 3. Data disclosing

4. Education and Training: The enterprises are required to educate their employees on pollution and environmental problems.

### 4. Education and Training of Employees

5. Monitoring: The enterprises must observe the emission standard of atmospheric pollutants set by laws. For this purpose, it is necessary to measure, monitor and record regularly the emission concentration of pollutants such as SO<sub>2</sub> in the flue gas.

### 5. Monitoring

6. Greening of power plant: In Japan, by Factory Location Law, it is obliged to secure 20% or more of the site area for green space in newly constructed power stations.

### 6. Greening of Power Station

7. Measures against accident and emergency: The director of the power station is required to coordinate with superior, to make manuals and to implement the employees' training always so as to take smooth action immediately to respond to the request from the local government.

### 7. Measures against Accident and Emergency

- Accident
- Emergency

For the detail information, refer to the pages at P.254~259 or E.281~288.

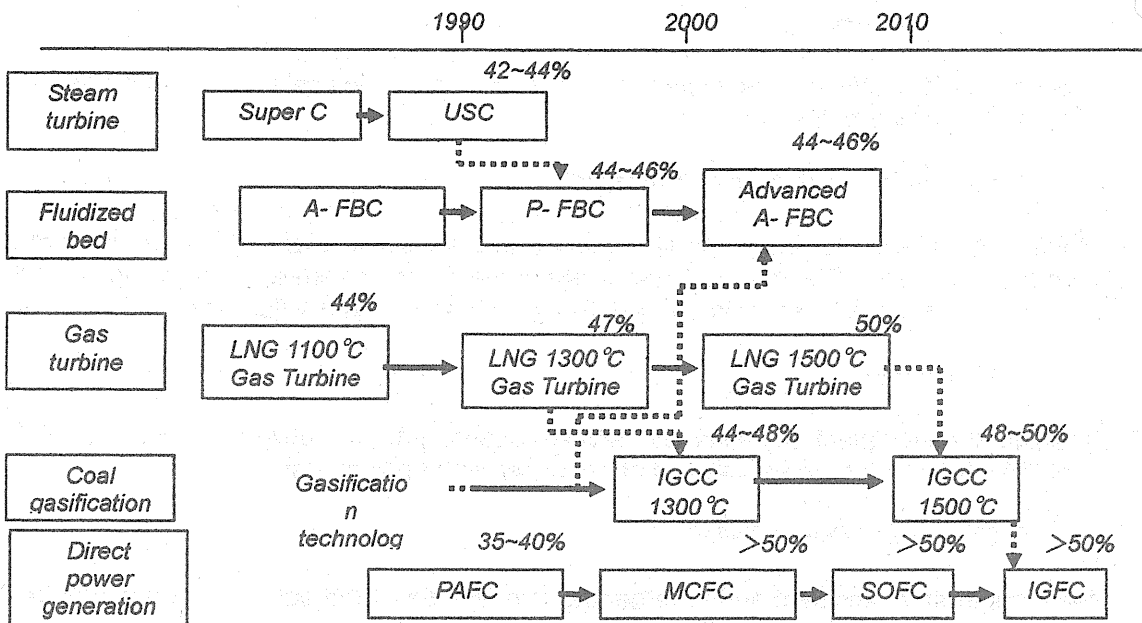
## 9. Energy Saving

The energy saving in electric power generation is as much as the decreasing of pollution load. It is necessary to promote the development of technology to achieving high efficiency and solve the difficult problems of coal-fired power plants.

$$\begin{aligned} & \underline{\text{Efficiency improvement}} \\ & \quad = \underline{\text{Energy saving}} \\ & \quad = \underline{\text{Pollution decreasing}} \end{aligned}$$

The high-efficiency power generation technologies and systems over the time series are shown in a slide.

In pulverized coal fired power plants, steam turbine of ultra supercritical 2-stage reheating cycle power generation system (USC) with the efficiency of 42~44%, fluidized bed combustion of atmospheric pressure fluidized bed combustion (A-FBC) and pressurized fluidized bed combustion (P-FBC) have been adopted. In coal gasification, integrated coal gasification combined cycle (IGCC) power generation method become to be adopted with high efficiency of 47%. In gas turbines used for LNG fired boiler, the turbine driven at high temperature of 1,500°C with high efficiency of 50% is under developing.



In direct power generation, phosphoric acid fuel cell (PAFC) is reaching at the stage of trial applications of 50~500 kW for public facilities, hotels, etc with co-generation system. Melted carbonate fuel cell (MCFC) is under 3rd stage development with capacity of 300 kW. Solid electrolyte fuel cell (SOFC) and gasification fuel cell (IGFC) are under developing.

For the detail information, refer to the pages at P.147~167 or E.109~139.