

Table 3-9 Energy Saving Rate Settings by Industry for Thailand

Industry	Energy saving rate
Agriculture & Fishing	2.0 / Year
Mining & Quarrying	2.0
Foods & Beverages	2.0
Textiles & Wearing	2.4
Wood & Wood Products	2.0
Paper & Printing	3.0
Chemical & Petroleum	4.0
Nonmetallic & Mineral	2.0
Basic Metal	2.0
Fabricated & Machinery	2.0
Electricity & Gas	3.0
Construction	2.0
Trades & Hotels & Resid.	2.0
Transport & Communication	2.0
Banks & Service	2.0

4. Reduction Technology of NO_x and Particulate Matters

4.1 NO_x Reduction Technology

4.1.1 Mechanism of NO_x Formation

Although the known compounds of nitrogen and oxygen include NO, NO₂, N₂O, N₂O₃, N₂O₄, N₂O₅, etc., those generated by the combustion of fossil fuel at general combustion facilities are mostly NO and NO₂, and the sum of the two or NO + NO₂ is called nitrogen oxide, NO_x. In the case of ordinary combustion facilities, such as a boiler, NO₂ accounts for the several to 10 Vol% of NO_x, so that most of the contents of NO_x may be considered to be NO. However, in the case of a combustion facility, for example, a gas turbine, in which combustion is carried out at a very high air ratio, though the concentration of NO_x is low, NO₂ may exceed the level of 50% of NO_x. NO generated in combustion can be divided into the following two types depending on the supply sources of its N:

- ① NO formed as a result that nitrogen molecules in the air are oxidized under the state of a high temperature; and
- ② NO formed during combustion from various nitrogen compounds contained in fuels.

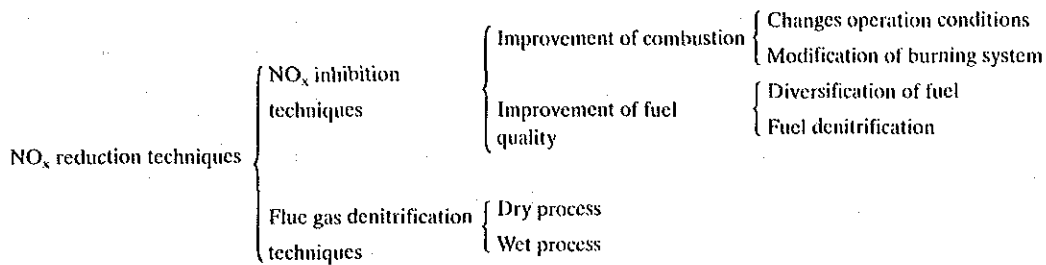
① is called Thermal NO_x since it is generated by a thermal reaction, whereas ② is called as Fuel NO_x since it is generated from the N content of fuel.

The formation mechanism is complicated in that there are two kinds of NO_x which differ greatly in the sources and mechanism of formation as described above and that all the N contents of fuel do not become NO_x unlike the case of SO_x. This results in the differences in reduction effect among NO_x emission sources even though the same technique for reduction is performed.

4.1.2 Classification of NO_x Controlling Technologies

NO_x controlling technologies include the NO_x inhibition technique (low NO_x combustion technique) and the flue gas denitrification technique as shown in Table 4-1. Improvement of combustion for the NO_x inhibition technique makes the combustion conditions in the furnace preclude NO_x from being formed as far as possible. Regarding fuel denitrification among the techniques for fuel improvement, no such technique as fuel oil desulfurization to remove sulfur content from fuel oil has yet been established for nitrogen content. However, since some nitrogen content is simultaneously removed during fuel oil desulfurization, using low sulfur fuel will become effective for NO_x reduction as well.

Table 4-1 Classification of NO_x Reduction Techniques



4.1.3 NO_x Inhibition Technique by Improvement of Combustion

(1) NO_x inhibition by low air-ratio combustion

NO_x is a compound formed by the reaction at a high temperature between nitrogen (N₂) and oxygen (O₂), which are the gas constituents of air. This is roughly divided into Thermal NO_x and Fuel NO_x based on the formation mechanism, and the amounts of their formation vary with flame temperature, oxygen concentration, and the residence time of gas in flame. Concluding first, the output of NO_x in flame can be inhibited by lowering the flame temperature, decreasing the oxygen concentration, and further shortening the residence time.

Low air-ratio combustion represents a way of lowering NO_x aiming to suppress the output of NO_x by burning the fuel at a decreased concentration of oxygen as one of the above mentioned means. In other words, it is an attempt to operate under the condition of the minimum possible volume of oxygen supplied to the combustion facilities which is required for combustion of fuel. It means that most of the oxygen in the air supplied to the combustion facilities is consumed for burning of fuel and is given no room for reaction with nitrogen to produce NO_x, thus achieving the reduction of NO_x.

In conventional burners, it is said that the maximum flame temperature related to the formation of NO_x is obtained at an air ratio of 1, that is, at slightly more excess air than in the case of a theoretical air requirement. If the air ratio is less than that, the temperature will decline, and even though larger than that, the temperature will decrease because oxygen is mixed. In addition, since the smaller the air ratio, the lower the concentration of oxygen becomes, the NO_x concentration will be eventually decreased when their effects overlap each other as a result of a low air ratio. Even in this case, whether the mixing condition of gas is good or not will of course become a problem. Comparing long and short flames, the NO_x concentration is higher in the short flame. In the case of the short flame, NO_x concentration increases at a smaller air ratio than that of the long flame. Thus, by the combustion at a low air ratio which decreases the concentration of oxygen, it cannot be explained that the reduction of NO_x is achieved only by the effect of the oxygen concentration. Figure 4-1 illustrates an example showing the relations between the concentration of oxygen in flue gas and the NO_x concentration. This diagram indicates a rapid decline in the NO_x concentration when oxygen becomes 1% or less, thus revealing the effect of combustion at a low air ratio. As shown in Figure 4-2, however, when an attempt is made to lower the air ratio to attain the reduction of NO_x, all the more sooty particulates will be generated.

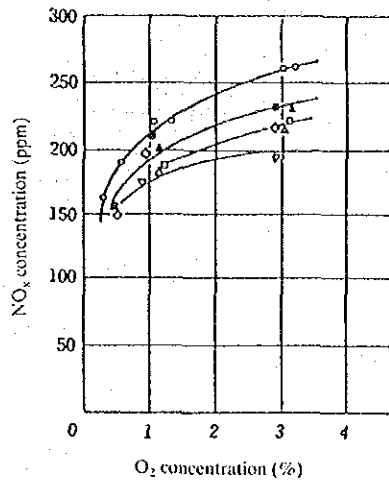


Figure 4-1 Typical Correlation between O₂ Content and NO_x Content in the Flue Gas

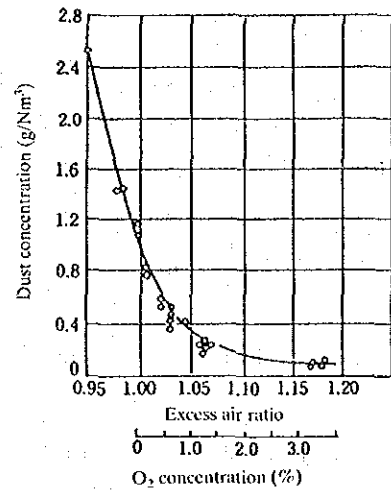


Figure 4-2 Typical Correlation between Dust Content and O₂ Content in Flue Gas

(2) NO_x inhibition by reduction of thermal load

The higher the flame temperature, the faster and the more the formation of NO_x becomes. Consequently, the reduction of NO_x can be attained by lowering the flame temperature. Considering the combustion calories of fuel entering the combustion chamber, it is thought that when the value of the volumetric thermal load of the combustion chamber (which means combustion calories input in unit volume of the combustion chamber within unit time and is represented in Kcal/m³ hr) is large, the flame temperature will rise and the NO_x generation will increase.

Figure 4-3 shows the relations between volumetric thermal load and the emission volume of NO_x at thermal electric power plants. In this case the emission volume of NO_x is shown by the generation volume of NO_x per calorie of the fuel entering the combustion chamber. It is well indicated that the larger the volumetric thermal load, the higher the rate of NO_x generation. Furthermore, Figure 4-4 shows the correlation between NO_x emission volume and load factor, that is, the ratios of the generation volume of vapor in actual operation to the rated generation volume of vapor. This diagram shows that when the load factor becomes smaller, the NO_x emission volume will decrease, and it can be seen that low load operation is a means to reduce the generation volume of NO_x.

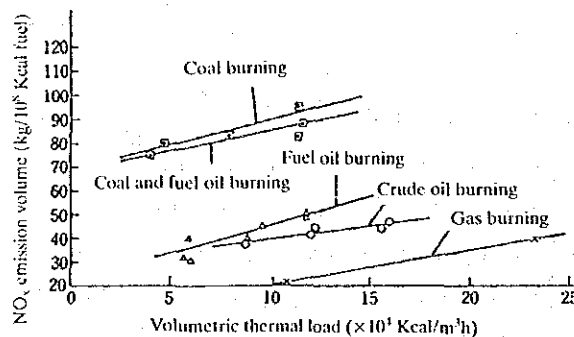


Figure 4-3 Typical Correlations between Volumetric Thermal Load and NO_x Emission Volume at Thermal Electric Power Plants

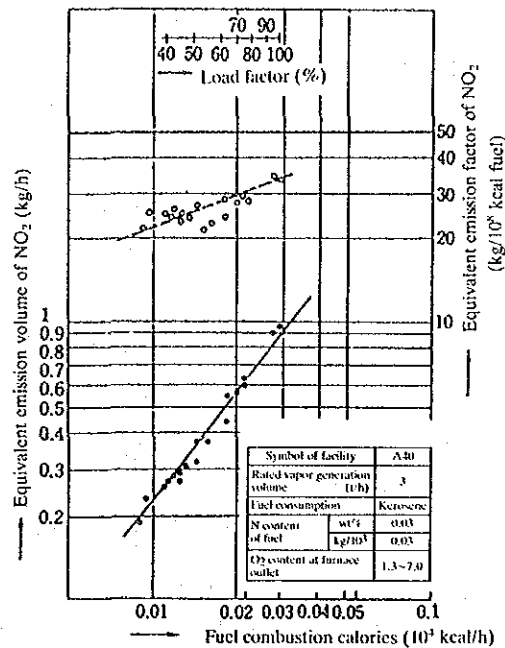


Figure 4-4 Typical Correlation between Boiler's Load Factor and NO_x Emission Volume

However, the simple lowering of the load will lead to the decline of the facilities operating rate, and further to the reduction of the factory's operating rate. Therefore, it is important to ensure energy saving and to avoid using wasteful fuel. This energy saving will enable us not only to inhibit NO_x, but also to suppress wasteful cost.

(3) NO_x inhibition by reduction of the temperature of air for combustion

There are many plants which are preheating air for combustion, such as large-size thermal electric power plants and glass melting furnaces. In these plants, to decrease this preheating temperature will lower the flame temperature, resulting in a countermeasure for NO_x. There is, for example, data demonstrating that obtaining NO_x emission volume for a boiler which preheats air using flue gas and for a boiler without air preheating, the NO_x emission volume of non-preheating is 10% smaller than that of preheating. Thus, to decrease the preheating temperature of air can be said to be a method of NO_x reduction and is being done as occasion demands. This method will, however, cause a problem of a decline in thermal efficiency as the decrease in the operating rate due to the lowered heat load as described in (2).

(4) Low NO_x burner

At present, low NO_x burners with various principles and mechanisms have been developed by each manufacturer. Since they only require relatively minimal modification of burners and their attachments in application, they can be said to be suited for not only new facilities but also existing facilities in medium- and small-combustion plants. They may well be the most effective for NO_x reduction of medium- and small-size plants. The low NO_x burners are classified into the following four types in terms of principle and mechanism:

- ① Mixing acceleration type
- ② Separated flame type
- ③ Self-recirculation type
- ④ Multi-stage combustion type

1) Mixing acceleration type

As shown in Figure 4-5, this burner rapidly mixes fuel and air by allowing the fuel jet and the air flow to collide approximately at right angles and thus create a very thin flame in a shape just like a hanging bell. In order to secure good mixing, the flow rate of air is relatively high, coupled with adoption of a feeding method in which the air is not divided between primary and secondary air as in the case of the conventional burners and all can be considered as primary air. By changing the ratio between the rates of the fuel jet and air flow, in addition, the flame shape can be varied within some range. Moreover, the flame becomes very thin and of a wide area, resulting in the good transfer of heat radiated from the flame itself, the less elevation of the maximum flame temperature, the shortened residence time of combustion gas at a high temperature, and a decrease in Thermal NO_x .

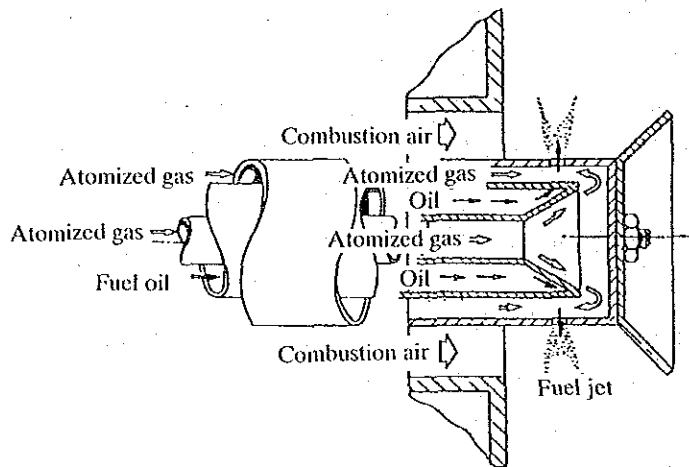


Figure 4-5 Low NO_x Burner of Mixing Acceleration Type

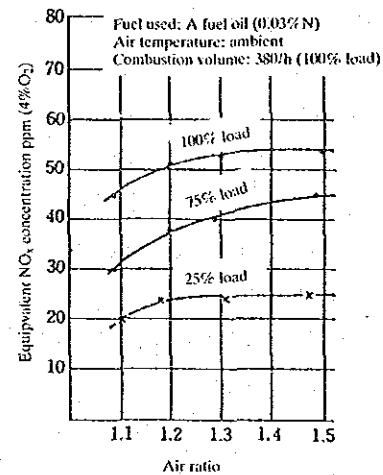


Figure 4-6 NO_x Emission Volume of Low NO_x Burner of Mixing Acceleration Type

Figure 4-6 shows the NO_x emission volume of this burner. The characteristic of this burner is that while the air ratio decreases, the NO_x concentration declines slightly, and the difference is relatively small. The flame diameter is not greatly affected by air ratio and load, with little change in the flame length up till 50% load.

2) Separated flame type

Figure 4-7 is one example of a separated flame type burner. This burner provides grooves in the end surface of the burner tip as in Figure 4-7 and separates the flame into a plurality of independent small flames, thus inhibiting thermal NO_x by lowering the flame temperature and shortening the residence time.

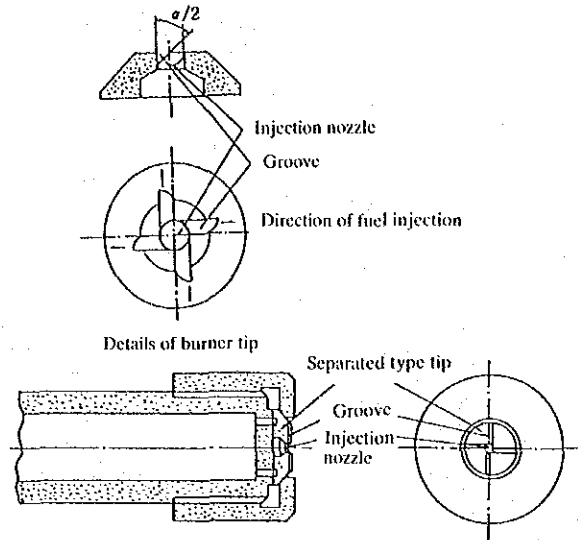


Figure 4-7 Low NO_x Burner of Separated Flame Type

This burners include atomization by oil pressure and atomization by two fluids, using steam. Figure 4-8 accounts for the effect obtained when a separated flame type burner and another inhibiting countermeasure are combined.

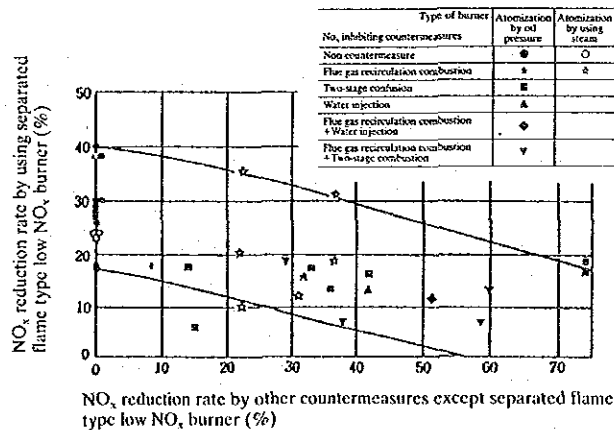


Figure 4-8 Comparison of NO_x Reduction Rate between Separated Flame Type Low NO_x Burner and Other Measures

3) Self-recirculation type

In this type, combustion gas inside the burner is forced to recirculate by the wake that is generated by air and the fuel jet to lower the O₂ concentration in the circulation range as well as make it closer to fuel evaporation and gas combustion, thereby attaining NO_x reduction. The wake means the flow of surrounding fluid that takes place in concomitance with the fast flow of air and fuel. This case is utilizing the nature that the fast flow of air and fuel

draws surrounding combustion gas and takes it into itself. Depending upon such intake of combustion gas, the self-recirculation type burner is divided into two kinds as shown in Figure 4-9.

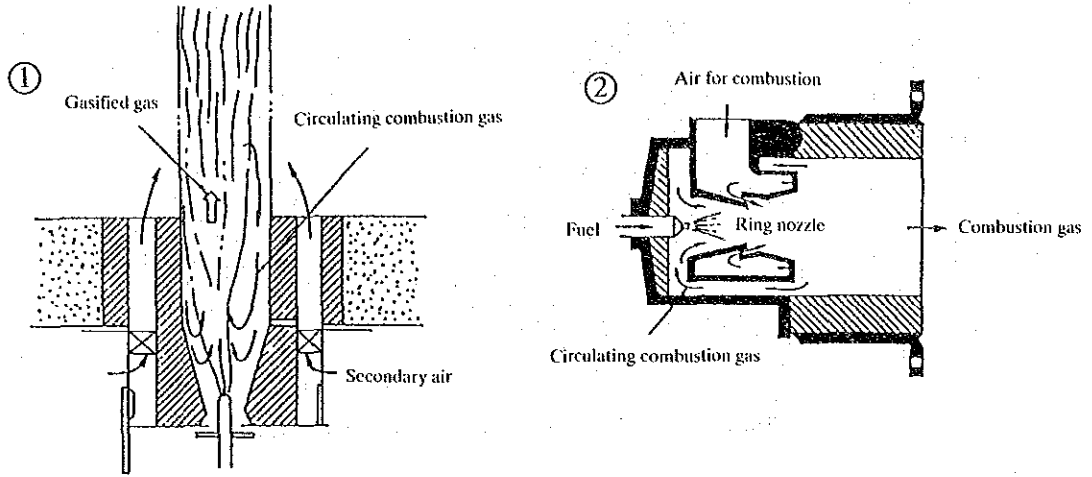


Figure 4-9 Low NO_x Burner of Self-recirculation Type

Figure 4-10 compares the NO_x emission volumes of this burner and a conventional tandem burner. The reduction rate of NO_x is about 25% to 45%. The flame length and diameter do not undergo any major change against the air ratio. However, since the flame size becomes relatively large, it is necessary to pay sufficient attention to match it with a combustion chamber when applied, for example, to boilers. In addition, this burner has a characteristic that there occurs no great change in the NO_x emission volume even if air preheating is enhanced.

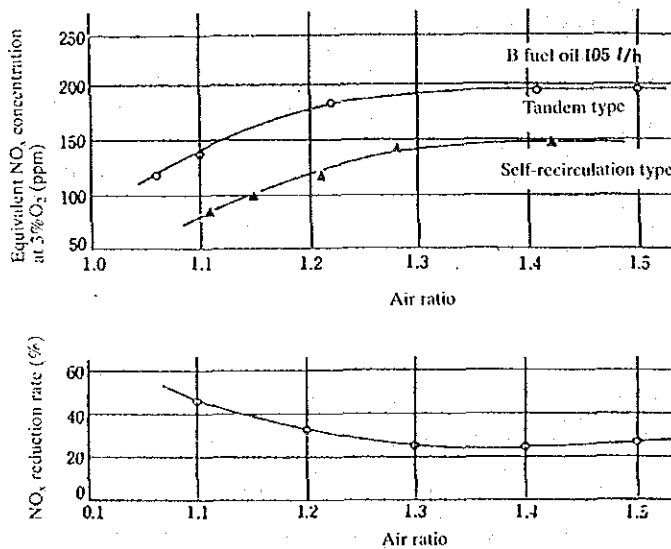


Figure 4-10 Comparison of NO_x Emission Volume between Self-recirculation Type Burner and Conventional Type Burner

4) Multistage combustion type

In this type, with the burner structure allowed to ensure multistage combustion such as two-stage combustion and off-stoichiometric combustion, the combustion condition with a low O_2 concentration is created in the first stage to inhibit NO_x . Multistage combustion means that air for combustion is divided into several stages (usually two stages) and then supplied, in the first stage of which the combustion condition with a low O_2 concentration is no doubt created. In the conventional combustion method as well, a similarly way of air supply has been adopted as divided into primary and secondary air. It may be considered that multistage combustion has further clarified the above conventional process. Figures 4-11 and 4-12 show the schematic structures of low NO_x burners of the two-stage combustion type for gas and for oil. Moreover, Figure 4-13 shows the inhibitory effect of this type on NO_x .

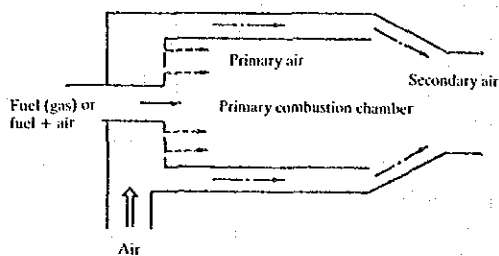


Figure 4-11 Low NO_x Burner of Two-stage Combustion Type for Gas

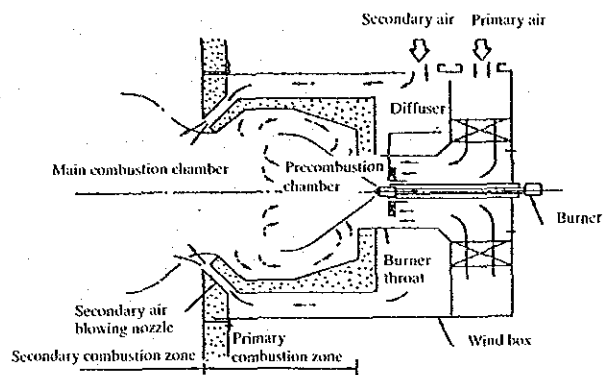


Figure 4-12 Low NO_x Burner of Two-stage Combustion Type for Oil

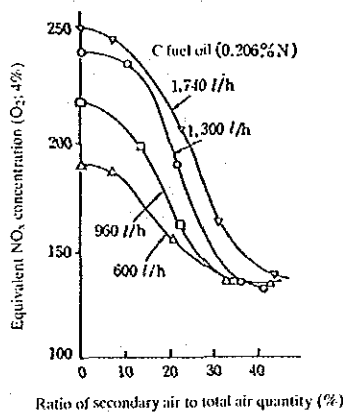


Figure 4-13 Effect of Low NO_x Burner of Two-stage Combustion Type for Oil

(5) Two-stage combustion

This method has the oldest history as an NO_x countermeasure for stationary combustion facilities. At the end of the 1950s, its development started out in the form of a countermeasure for thermal electric power generation boilers in the U.S. According to the principle of this method, as shown in Figure 4-14, air for combustion is divided into two stages and supplied; in the first stage the fuel is burnt at an air ratio less than 1 (normally 0.8 to 0.9), and subsequently in the second stage of down flow, perfect combustion is performed by feeding air to meet the shortage for a prescribed air ratio.

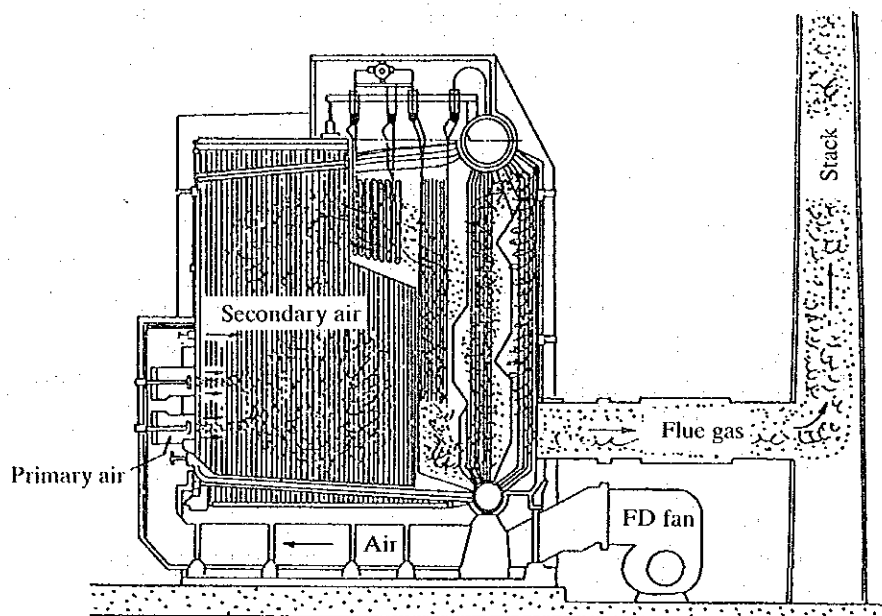


Figure 4-14 Two-stage Combustion

In two-stage combustion, NO_x inhibition can be performed by combustion with a low O_2 concentration in the first stage and the relatively prompt combustion following the point of air blowing in the second stage. Since low O_2 combustion is in a pre-stage, the air requirement for perfect combustion is slightly larger than that for ordinary combustion. This method, as shown in Figure 4-15, has the reduction effect on both Thermal NO_x and Fuel NO_x , varying its degree depending upon the air ratio in the first stage and an overall air ratio, but showing a 50% to 30% reduction in Thermal NO_x and 50% or less in Fuel NO_x .

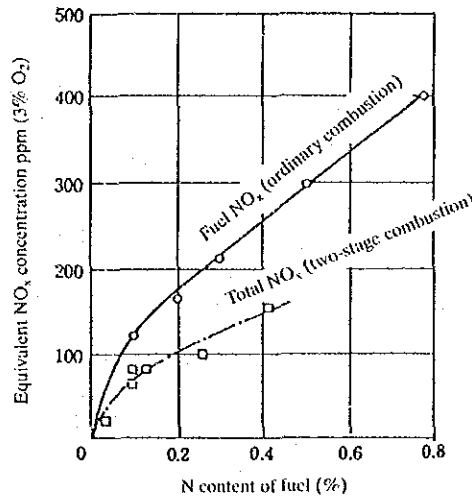


Figure 4-15 Effect of Two-stage Combustion on NO_x Reduction

When the two-stage combustion is adopted, special attention must be paid to an increase in the generation volumes of unburned contents including sooty particulates, CO, and HC. While CO and HC are often overlooked since they are rarely measured, some boilers applying the two-stage combustion may emit 500 ppm or more of CO. This is a substantial increase taking into consideration the case of conventional boilers which, except for small ones, emit 10 ppm to 20 ppm or less. Moreover, it has been reported that the two-stage combustion makes it liable to produce unstable combustion at large-size plants. Though temporarily, this is considered because combustion with a shortage of air is allowed to take place at the initial stage of combustion and because the velocity of air in the burner is lowered, resulting in the aggravation of the mixing characteristic of fuel and air in the furnace.

(6) Off-stoichiometric combustion

In large-size boilers, many burners are usually arranged in the front surface of the combustion chamber or an opposite surface to it. According to the conventional combustion process, fuel and air have been fed to these burners as uniformly as possible, because this leads to good combustion in the condition of a low air ratio, enabling the improvement of the boiler efficiency and simultaneously the suppressed formation of SO₃, which causes the corrosion of low temperature regions. This combustion method with a reduced air ratio is called low excess air combustion or low O₂ operation, which inhibits NO_x emission. This accounts for the off-stoichiometric combustion as a method that attempts to positively make the flow of fuel and air uneven, though not completely random, contrary to the uniform feed of fuel and air that has been pursued as a desired course.

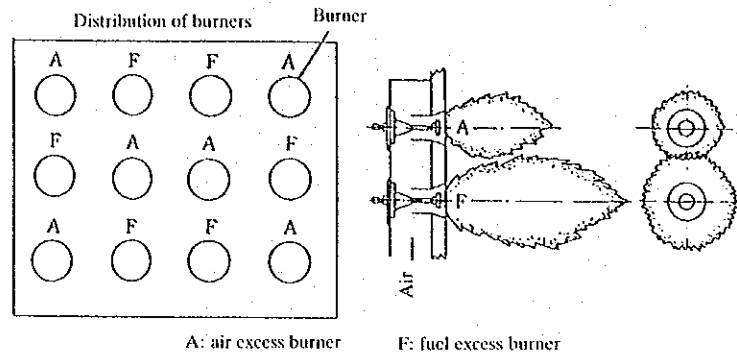


Figure 4-16 Off-stoichiometric Combustion

In the actual method, as shown in Figure 4-16, with the allocation of air quantities conventionally made uniform, fuel for some of many burners is increased to be used in a state of concentrated fuel, followed by the allocation of air excess burners or the feed inlets of air alone around the said burners. The principles and effects of inhibition may be thought to be of the same degree as those in the case of two-stage combustion. As compared with two-stage combustion, however, the excess air blowing positions are nearer to the fuel excess burners and can be evenly distributed, so that this method ensures a better mixing of fuel and air in the second and subsequent stages and is therefore thought to be superb in preventing the generation of sooty particulates, CO, and HC. Figure 4-17 shows the reduction effect of Thermal NO_x (no Fuel NO_x fuel is natural gas) due to this off-stoichiometric combustion.

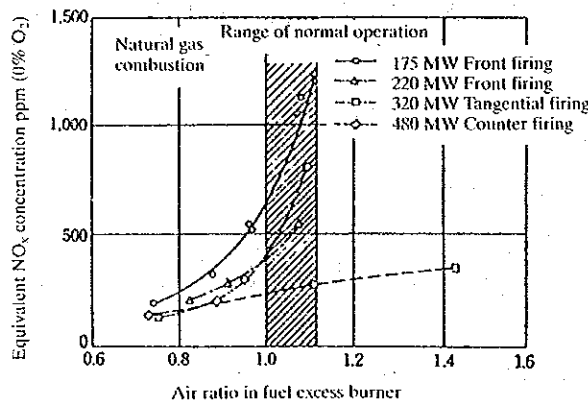


Figure 4-17 Effect of Off-stoichiometric Combustion

(7) Flue gas recirculating combustion

As shown in Figure 4-18, this method attempts to mix part of low-temperature flue gas into air for combustion and then burn it, thereby inhibiting NO_x through the decline of the combustion temperature. Since flue gas is a result of perfect combustion, its major ingredients include N₂, CO₂, H₂O, and O₂, none of which are burnt to heat even when fed again to the combustion chamber. Moreover, since they are cooled down to the state of flue gas, that is, to some 200°C, they will

receive the heat emitted by a new fuel, decreasing the temperature inside the combustion chamber. Although such a decrease in temperature, as shown in Figure 4-19, enables the reduction of Thermal NO_x to a considerable extent, there is little effect on Fuel NO_x as shown in Figure 4-20.

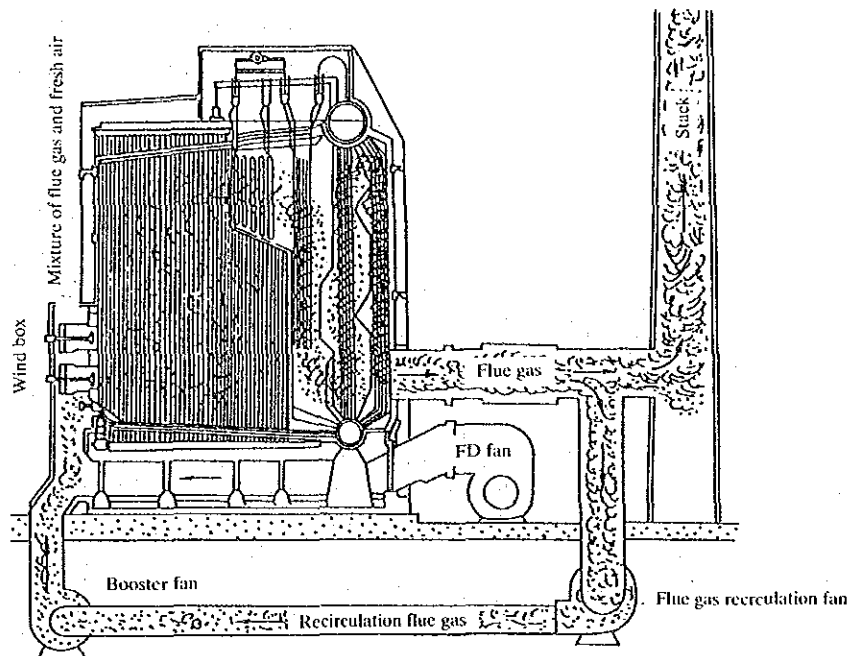


Figure 4-18 Flue Gas Recirculation Combustion

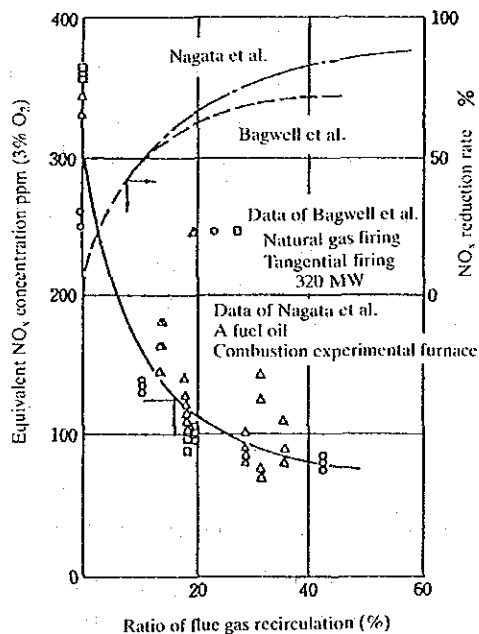


Figure 4-19 Effect on Thermal NO_x Reduction of Flue Gas Recirculation (when using gas or low N content fuel)

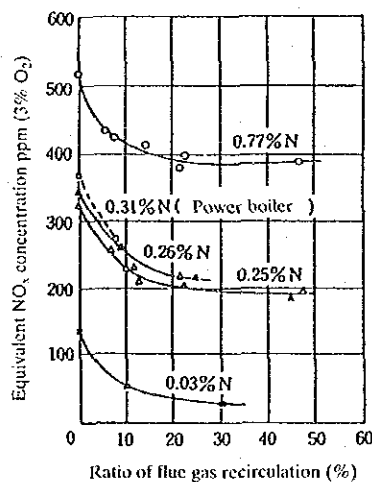


Figure 4-20 Comparison of Effect for Flue Gas Recirculation among Different N Contents in Fuel

In the case of flue gas recirculation combustion, this is not a recommendable countermeasure for medium- and small-size plants because many new apparatuses must be installed, such as those for the duct and recirculation blowers, and space must be allocated for them.

(8) Water or steam injection

When water or steam is injected into the combustion chamber for burning, the combustion temperature will also decline as in the case of flue gas recirculation combustion, so that NO_x can be inhibited. Water or steam so injected will get rid of generated heat from fuel combustion. In this case, since the decrease in the combustion temperature is primarily responsible for NO_x reduction, it may be thought that this method has effect on Thermal NO_x , but no effect on Fuel NO_x . There are three methods of injecting water or steam into the combustion chamber, such as:

- ① Water or steam injection into air for combustion;
- ② Water or steam injection into some position in the combustion chamber (a method of increasing steam for atomization in a burner with steam used as an atomization medium among two fluid types is also included in this category); and
- ③ to use an emulsion fuel formed by mixing water with the fuel.

When water or steam is injected, if the injection quantity is the same, injecting in the combustion region alone will exert better effect for temperature reduction than spreading over those regions not involved in combustion in the combustion chamber as a whole. Therefore, it may be considered that ② or ③ will have a greater NO_x reduction effect than ①. In the case of ②, while the injection position becomes an important affecting factor for the same reason, it is generally considered better to have the position as close to the burner as possible. When the same quantities of water and vapor are injected, water is thought to lower the temperature to the extent equivalent to the latent heat of steam, resulting in a higher NO_x inhibitory effect. The method ② is fit for an NO_x countermeasure taken when using good quality fuels such as gas, kerosene, and A fuel oil because it can be performed by relatively small modification, for example, providing the injection nozzle for water or steam in the vicinity of the burner. It is necessary, however, to be prepared for some decrease in thermal efficiency due to the increase in heat held by flue gas. Especially when steam is used, the loss in terms of energy will become great.

(9) Summary

Generally speaking, inhibiting countermeasures by changing operating conditions can be applied even to currently operating facilities without any economic burden, but they have in return no great reduction effect, and many of them cause problems in actual operation as well. On the contrary, new combustion methods are desirable in that they have a great degree of freedom for NO_x reduction countermeasures, but when an attempt is made to apply them to existing facilities in operation, many of them require considerable modification of facilities. Table 4-2 summarizes the NO_x inhibiting techniques by the combustion improvements that have been performed to date.

Table 4-2 Characteristics of Various NO_x Inhibiting Countermeasures

Method of inhibition	Thermal NO _x			Fuel NO _x			H	Disturbances to be considered in advance				Remark			
	Principle for inhibition			Principle for inhibition				I	J	K	L				
	A	B	C	D	E	F							G		
Operating conditions	Change of the range of operating air ratio	⊙	⊙	⊙	Δ	○	○	⊙	Δ				×	Low excess air combustion at large-size plants. Low excess air combustion has effect on fuel NO _x . Except for especially high air ratio, mark × for L shows upon a shift to low air ratio side.	
	Change of mixing characteristic in combustion chamber by operation of air register	⊙	⊙	○	Δ		Δ	Δ	⊙	○		○	○	When mixing becomes poor: F and G; mark ○, I, K and L; mark ×. When mixing becomes better: F and G; mark ×, I, K and L; mark double ○.	
	Reduction of volumetric thermal load in combustion chamber	⊙		○	○				⊙	Δ	×	×			
	Reduction of preheating of air for combustion	⊙		○	○				⊙	×	×	×			
Method of combustion	Mixing acceleration type	○		⊙	⊙			○						⊙	
	Separated flame type	⊙		⊙	⊙			○							
	Self-recirculation type	○	⊙	○	⊙		○	○							
	Multistage combustion type		⊙		⊙		○	○							
	Two-stage combustion		⊙		⊙		○	○	○					×	
	Off-stoichiometric combustion		⊙		⊙		○	○	○					×	To be applied only to multi-burner facilities
	Flue gas recirculation combustion	⊙		○	⊙				Δ	×				×	Mark × for L is when excess. When qualified, there is a great possibility of improvement in sooty particulates and CO.
Water or steam injection	⊙		○	○				○	×				○	L: a great possibility of improvement in sooty particulates.	
Other	Fuel conversion	⊙	⊙	⊙	□	○		⊙	Δ					⊙	Conversion from coal and fuel oil to gas or to low N content fuel: mark □ for D is due to a possible increase in thermal NO _x upon conversion from fuel oil to gas.
	Shape of combustion chamber	⊙		○	⊙				Δ						

Thermal NO_x

- A: Decrease in combustion temperature
- B: Reduction of O₂ concentration in combustion range
- C: Decrease of residence time in high temperature range
- ⊙: particularly relevant
- : relevant
- D: Degree of inhibitory effect
- ⊙: relatively high
- : not too high
- Δ: relation between inhibition method and effect is not certain, but varies from one facility to another.
- : no effect clarified by study results to date

Fuel NO_x

- E: Reduction of nitrogen compounds in fuel
- F: Reduction of O₂ concentration in initial combustion range
- : develops action
- Δ: differs in each facility
- G: Degree of inhibitory effect
- ⊙: relatively high
- : not too high
- Δ: differs in each facility
- H: Difficulty when adopting as a countermeasure
- ⊙: possible even with existing facilities
- : requires some modification
- Δ: requires substantial changes of facilities

Disturbances to be considered in advance

- I: Decline of thermal efficiency
- J: Decline of power
- K: Enlarged facilities
- L: Increases in other pollutants (sooty particulates, CO, H₂C (hydrocarbon))
- ×
- : differs in each facility
- ⊙: expected to be improved
- Existing: when applied to existing facilities
- New: when applied to new facilities

4.1.4 NO_x Inhibiting Techniques by Fuel Conversion

In order to reduce the generation volume of NO_x by converting fuels, it is firstly necessary to understand in advance to what degree NO_x will be generated when what fuel is burned. Then, the values of various fuels will be hereunder compared using a yardstick which will be the NO_x emission factor. The NO_x emission factor is the rate of NO_x emission showing to what degree NO_x is emitted when, for example, a unit volume of fuel is burnt, in order to indicate from what the emission volume of NO_x, stated in kg, has resulted. That is to say, assume that 55 kg of NO_x is emitted as a result of burning 10 kl of fuel oil, the emission factor of NO_x is to be 5.5 kg-NO_x/kl fuel oil. Of course, the fuel consumption is shown in tons for coal, Nm³ for fuel gas, but this does not permit the comparison of their combustion volumes. Therefore, the consumption is often indicated in heat value.

The NO_x emission factor is obtained by statistically processing and estimating many data on NO_x emission volumes and fuel consumption that are measured at various facilities. Namely, the NO_x emission factor can be defined as "a statistical ratio obtained by dividing the emission volume of a pollutant into the level of human activities when the said pollutant is emitted in the air in concomitance with human activities such as fuel burning and industrial production." While emission factors have been compiled and published by the U.S. government over many years, in Japan as well, for example, the Air Quality Bureau of the Environment Agency has measured air pollutants and exerted efforts on the calculation of the factors.

Table 4-3 shows the NO_x emission volumes per fuel consumption volume summarized by using the results of a survey on the actual conditions of NO_x emission volumes at stationary combustion facilities conducted by the Air Quality Bureau of the Environment Agency. As seen from this table, the NO_x emission volume varies depending upon the fuel types. It is low in the case of gaseous fuels, yet varies from one type of gas to another. In the case of liquid fuels, in addition, the emission volume likewise varies depending upon their types, showing less NO_x emission volume from light oil than heavy oil. On the other hand, it can be seen that the largest NO_x emission volume is attributed to coal. These data demonstrate that fuel NO_x is less emitted from gas and light oil than heavy oil and coal. However, this tendency is marked when the furnace temperature is relatively low as in case of a boiler in particular, whereas it is not notable in the case of a glass melting furnace and cement furnace which have high temperatures and produce large volumes of thermal NO_x. As understandable from the above description, fuel conversion is a considerably effective NO_x prevention countermeasure, and is now being used by many stationary combustion facilities.

Table 4-3 NO_x Emission Factors by Facility and by Fuel (NO₂ kg/10⁸ Kcal Fuel)

Power boilers

Fuel	No. of measured plants	Emission factor
Coal	1	128.0
Coal + fuel oil	1	105.3
Fuel oil	26	63.0
Crude oil	2	56.5
Natural gas	1	38.9

Industrial boilers

Fuel	No. of measured plants	Emission factor
C fuel oil	79	56.6
B fuel oil	10	40.5
A fuel oil	58	25.2
Kerosene	34	20.7
C fuel oil + gas	3	35.5
Town gas	15	24.0
LPG	6	32.4

Steel heating furnace

Fuel	No. of measured plants	Emission factor
C fuel oil	13	55.8
B fuel oil	4	56.4
A fuel oil	9	37.4
Gas oil	2	42.8
Kerosene	7	17.4
Natural gas	3	14.8

Oil heating furnace

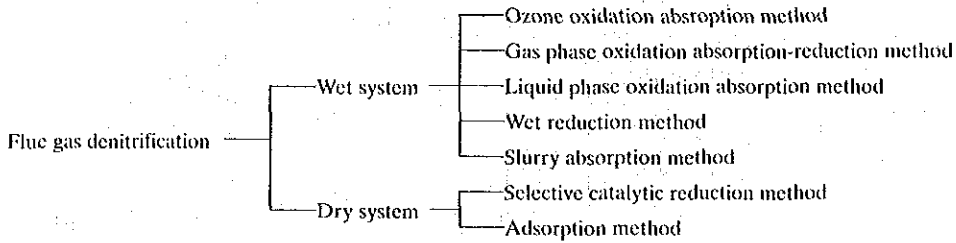
Fuel	No. of measured plants	Emission factor
C fuel oil	5	34.6
C fuel oil + byproduct gas	3	34.5
Byproduct oil	4	28.4
Byproduct oil + byproduct gas	3	22.2
Byproduct gas	8	45.4
LPG	1	19.8

Note: Each of the emission factors indicated in the above table is the average value of NO_x emission rates (NO₂ kg/10⁸ kcal fuel) per facility obtained from NO_x emission volumes and fuel combustion volumes at the measured facilities in the stated number. Therefore, in the case that the number of measured facilities is 1, the measured emission rate is shown as it is. Generally, it may be thought that the larger the number of measured facilities, the higher is the confidence. The heat value is the higher calorific value.

4.1.5 NO_x Reduction by Flue Gas Denitrification

Flue gas denitrification has two types of systems, wet and dry, as shown in Table 4-4. The wet system flue gas denitrification is a process in which waste gas is well washed with a liquid, for example, an alkali solution, followed by the absorption of NO_x in waste gas into this solution for its removal. By the dry system flue gas denitrification, on the other hand, NO_x in flue gas is decomposed by a decomposing gas under the presence of a catalyst, or is adsorbed by a granular absorbent, and is then removed.

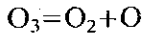
Table 4-4 Classification of Flue Gas Denitrification



(1) Ozone oxidation absorption method

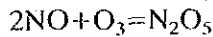
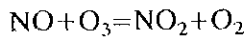
There is a waste gas denitrification method using ozone as an oxidizer to convert most of the NO_x in waste gas into a form that is easy to absorb, in which water or an alkali solution is used as a washing solution.

Ozone has far greater oxidizing power than oxygen. When contact with a substance which is liable to be oxidized, ozone develops a reaction as in the following equation, readily releasing atomic oxygen to oxidize the substance:



When ozone is added into waste gas, NO in waste gas will be oxidized to N₂O₅ or NO₂, which is absorbed by water or an alkali solution in the absorption tower.

Oxidation and absorption reactions to water when water is used for washing are shown by the following equations:



In this case NO_x is recovered as nitric acid; dilute nitric acid so obtained is concentrated into about 60% nitric acid in a fractionating tower. This method is advantageous in that since ozone is used as an oxidizing agent, only oxygen is produced in oxidizing NO_x, with no other pollutant brought in the reaction system. However, it involves some problems such as: there has been no great progress in the enlargement of the ozonizer size which produces ozone by high pressure discharge; and power consumption is large. The ozone oxidation absorption has been used for denitrification of waste gas at thermal electric power plants exclusively firing natural gas with an operation capacity of 100,000 Nm³/h. In this case, NO_x is recovered as nitric acid with flue gas washed with water, leading to the confirmation of high performance.

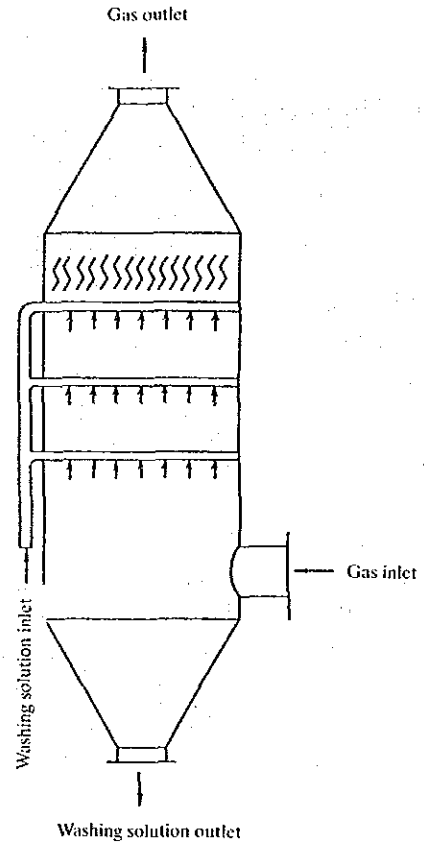
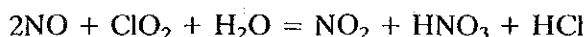


Figure 4-21 Spray Tower

(2) Gas-phase oxidation/absorption reduction method

This method oxidizes NO_x in flue gas with chlorine agents centered upon chlorine dioxide on a gas-phase basis and uses a sodium sulfite aqueous solution as an absorbent to absorb it, thus ensuring the reduction of NO_x to NO_2 . This method can also use ozone as an oxidizing agent, and is characterized by the processes of desulfurization and denitration which can also treat sulfur dioxide contained in flue gas. In this process, as shown in Figure 4-22, a cooling tower is first used, allowing flue gas to be humidified and cooled with water as well as leading chlorine dioxide, an oxidizing agent, into flue gas after removal of dust. This causes NO in flue gas to develop the reaction as shown in the following equation, so that a half becomes NO_2 , and the remaining half is changed into nitric acid:



Then, flue gas is fed to a plate tower using sodium hydroxide as an absorbent, where desulfurization and denitration take place simultaneously. That is to say, while flue gas is washed with recycled sodium hydroxide solution, sulfur dioxide in flue gas is absorbed, leading to the formation of sodium sulfite as shown in the following equation, which then reduces NO_2 , produced by the oxidizing agent, resulting in sodium sulfate as in the equation:

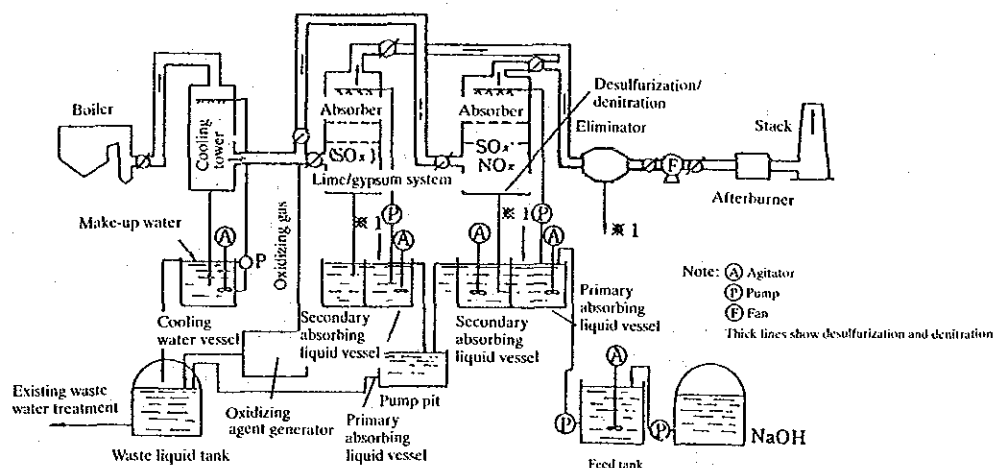
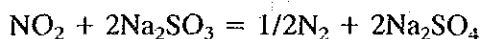
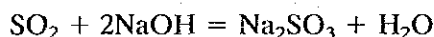
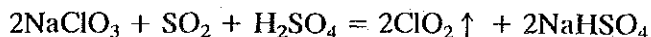
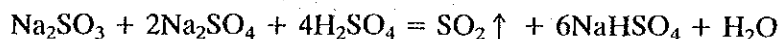


Figure 4-22 Flowchart of Process by Gas-phase Oxidation/Absorption Reduction (62,000 Nm³/h)

Chlorine dioxide used for oxidation of NO in flue gas is generated by allowing its action on sodium chlorate using sodium sulfite remaining in the washing solution. This reaction is as follows:



This process has already been used for treatment of flue gas from a boiler or heating furnace. Figure 4-22 shows the flowchart of a system for treatment of flue gas from a boiler with a treatment

volume of 62,000 Nm³/h. Table 4-5 shows the reduction conditions at the absorber in this process, and Table 4-6 illustrates running data. In this method, both desulfurization and denitration rates are high, and are expected to reach 99.5% and 95%, respectively. The problems for this process can be identified as operation control and cost attributable to the use of many agents, coupled with a problem in waste water treatment.

Table 4-5 Reduction Conditions at Absorber

Item	Values
1) Operating conditions of absorber	
Space velocity	3~6 m/sec
Gas liquid ratio	2~10 l/m ³
No. of trays	4 trays
2) pH in circulation of absorbing solution	6~8
3) SO ₃ concentration in circulating absorbing solution	10~100 g/l (Na ₂ SO ₃)

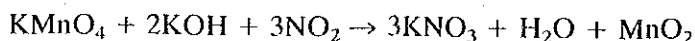
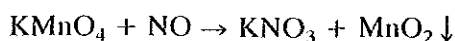
Table 4-6 Running Data of Gas-phase Oxidation Reduction Process

Test No.	Space velocity (m/sec)	Pressure loss (mm H ₂ O)	SO ₂ concentration (ppm)		NO _x concentration (ppm)	
			Inlet	Outlet	Inlet	Outlet
1	5.85	210	770	4	240	14
2	5.85	210	810	4	245	12
3	5.70	200	780	4	250	13
4	5.70	200	800	5	238	15
5	5.70	200	800	4	260	10
6	5.91	215	810	4	242	14
7	5.90	215	810	4	270	18
8	5.48	190	790	4	255	19
9	5.67	195	750	4	260	17
10	5.70	200	740	4	263	14
11	5.81	205	780	5	268	18
12	5.81	205	800	5	248	15
13	5.90	215	790	5	250	12
14	5.70	200	810	5	260	15
15	5.81	205	810	5	258	13

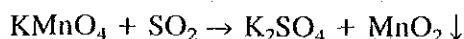
(3) Liquid-phase oxidation/absorption method (MON method)

The above described two methods of flue gas denitration are those which allow gaseous materials such as ozone and chlorine dioxide to act on NO, a major ingredient of NO_x of flue gas for oxidation and let a washing solution absorb it. These are called gas-phase oxidation/absorption methods. In the liquid phase oxidation/absorption method, for example, flue gas is washed with a washing solution which is formed by dissolving a manganese oxyacid salt (having oxidation capability) in an alkali solution. That is to say, in this method NO in flue gas is oxidized with the manganese oxyacid salt in a washing solution to fix and absorb it as nitric acid. It is typically a MON method.

The reaction with potassium permanganate as an oxidizing agent and potassium hydroxide as alkali are shown as follows:



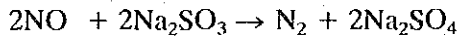
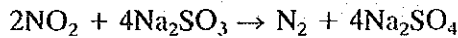
Moreover, sulfure dioxide in flue gas is likewise absorbed as follows:



Thus, the MON method has a characteristic that it can also perform desulfurization of flue gas simultaneously. Since MnO_2 generated has a good sedimenting property, it is readily filtered and can be easily separated from the washing solution. Therefore, it can be recovered and fed to the regeneration process for electrolytic oxidation and then be reutilized. With regard to the performance of the MON method, an experiment with the packed tower resulted in the data showing an elimination rate of 90% to 95%. As for the consumption of potassium permanganate, since 1 mol (158.03g) is equivalent to 1 mol each of NO and SO_2 (NO: 30g, SO_2 : 64g), 0.19kg of NO and 0.04kg of SO_2 can be treated with 1kg of potassium permanganate.

(4) Wet reduction method

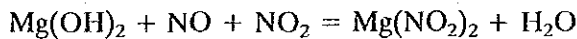
This is a process of reducing NO_x in flue gas to nitrogen by washing with a sodium sulfite solution. Its basic reactions are as follows:



Although this method has an advantage that NO_x in flue gas is reduced to nitrogen, sodium sulfite is oxidized, leading to byproduction of sodium sulfate.

(5) Slurry absorption method

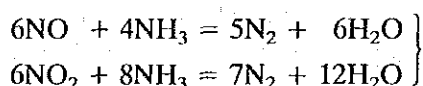
When NO and NO_2 are, as described above, present in an equal mol or at an equal concentration in flue gas, it can be absorbed with an alkali solution. Then, this method attempts to adjust NO_x in flue gas to equalize the concentrations of NO and NO_2 in advance and prepare magnesium hydroxide in the form of slurry for contact with them, thus aiming at absorption of NO_x as magnesium nitrite. This reaction is represented by the following equation:



In this case, magnesium nitrite obtained undergoes thermal decomposition to be reutilized as magnesium hydroxide. NO generated in this process is oxidized to nitric acid, part of which is added into flue gas to make up for NO_2 , so that NO and NO_2 are adjusted to have an equal concentration in flue gas. While desulfurization of flue gas can be performed by this method, it has shortcomings such as a slow reaction rate and an enlarged system size. In addition, this method can be done by using calcium hydroxide instead of magnesium hydroxide.

(6) Selective catalytic reduction by ammonium

The catalytic reduction method, in which NO_x in flue gas is catalytically reduced with ammonium, is widely used because it is convenient due to the selective reduction of NO_x by ammonium at a certain range of temperature, and its reaction proceeds as the following equation:



Though the description is a sometimes duplicated, the above selective reduction does not mean that NO_x is also allowed to react with oxygen or sulfur dioxide in flue gas as in the case of reduction using, for example, methane or carbon monoxide, but that ammonia is overwhelmingly liable to react with NO_x and therefore appears to reduce NO_x selectively. Since reduction with carbon monoxide or methane involves not only reduction of NO_x , but also reaction with oxygen or sulfur dioxide, there arise the problems that the reduction agent is to be consumed for other purposes than denitration and that this consumption or combustion may cause the temperature to rise. The required quantity of ammonia is determined dependent upon the amount of NO_x to be treated, specifying 1 mol (17g) of ammonia against 1 mol (30g) of NO. That is to say, NO which can be treated with 1 kg of ammonia accounts for 1,318 Nm^3 . It is reportedly a problem of this process that the reaction temperature is considered to range from approximately 250°C to 425°C. This is because if the temperature of flue gas is generally lower than the said temperature, gas must be heated with, for example, a heat exchanger, resulting in an increase in equipment cost as well as considerable energy consumption.

A next problem is catalyst. Because the reaction rate of this reduction is low, the nature and quantity of a catalyst may involve a problem if it is required as described above. First of all, catalysts include noble metals and non-noble metals. It is also said that in the case of a noble metal catalyst the reduction of NO_x does not proceed to nitrogen, causing the presence of some NO_x . However, the important problem for the catalyst is poisoning. The catalyst itself possesses no catalytic action, but when a quite small amount of a substance is added, its catalytic action may be markedly enhanced. This enhancing action is called acceleration, and the added substance is termed an accelerator. On the contrary, some substances when added to the catalyst lower the catalytic action considerably. Those substances are called poison and their action is referred to as poisoning. This may be applied to the catalysts used for the selective catalytic reduction of NO_x by ammonia, so that various accelerators have been studied coupled with the investigation of countermeasures for poisoning. The most critical problem is the poisoning effect of pollutants such as dust and sulfur dioxide on denitrating catalysts. Many of the currently available catalysts undergo the said poisoning and lose their activity. This has also led to the appearance of many catalysts which can develop the catalytic reduction of only clean flue gas including that of gas fuels containing no sulfur dioxide and the flue gas of light oil burning. Some catalysts, however, have been developed which can also denitrate dirty flue gas containing the above mentioned pollutants, yet the deterioration of catalytic activity seems unavoidable when flue gas is too dirty.

As a result, it is also under study that with a dust collector and a desulfurizer installed before an NO_x removal system, flue gas is cleaned in advance, and is then denitrated. In this case, however, since the use of, for example, a wet flue gas desulfurizer allows the temperature of flue gas to decline to 50°C to 60°C, the resulting elevation of denitration temperature will lead to the consumption of substantial energy. This problem has invited attention to further development of catalysts in the future. Next, the consumption of catalysts is worth noting since the catalysts are expensive. The amount of a catalyst is generally indicated in a value showing what m^3 of flue gas can be denitrated per m^3 of catalytic layer and per hour. This is called "Space Velocity," which is abbreviated as SV. Since SV is a value obtained by dividing the flow rate of flue gas (m^3/h) by the

volume of the catalytic layer (m^3), it is shown in the unit of $m^3/h/m^3$ (h^{-1}). While a larger SV is desirable, it is expected to be $7,000 h^{-1}$ in this case. Catalysts are in various forms such as granule, pellet, and ring molding. With a reactor packed with the catalyst, the above forms are especially related with the accumulation of dust contained in flue gas and further with the loss of catalyst along with the above mentioned SV.

(7) Reduction method by other reducing agents

NO_x in flue gas can be reduced, as described above, not only by ammonium, but also by carbon monoxide or methane. These reducing agents, however, do not reduce only NO_x in flue gas, but react with oxygen to heat. As a result, they consume a large amount of the reducing agent, and would be economically undesirable unless the above heat is recovered. In other words, they do not constitute the selective catalytic reduction method. Figure 4-23 is a flowchart of a flue gas denitration system with carbon monoxide as a reducing agent and using a specific catalyst. This is a system installed for treatment of boiler flue gas, with the volume of treated gas: $10,000 Nm^3/hr$; the composition of treated gas: NO_x 150 to 200 ppm; and sulfur oxides: 250 to 350 ppm.

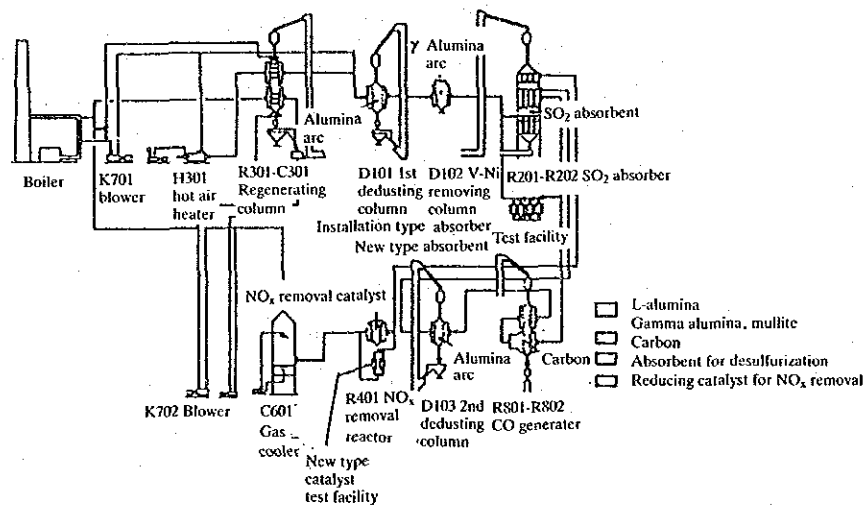


Figure 4-23 An Example of Non-selective Catalytic Reduction Type Waste Gas Denitration System

In this system, sulfur oxides and dust are removed and led to the NO_x removal reactor, with a flue gas desulfurizer and a dust collector installed in front as in the illustration, and it then removes NO_x and sulfur oxides in flue gas up to 1 to 5 ppm and 1 to 2 ppm, respectively, and exhausts it. This non-selective reduction method causes catalyst deterioration, the same problem as the faced in the ammonia selective reduction method. In addition, it is asserted that it is doubtful whether the system is applicable to flue gas with high concentrations of oxygen and sulfur oxides in view of heat absorption.

(8) Adsorption method

The method of adsorbing NO_x with activated carbon or a molecular sieve can be regarded possible as a principle like activated carbon adsorption in the flue gas desulfurization techniques.

However, putting it to practical use is said to be relatively questionable for the following reasons: the lower the temperature of flue gas, the larger the volume of adsorption becomes; NO adsorption is smaller than that of NO₂; and, moreover, moisture impairs adsorption.

4.2 Particle Material Reduction Technology

Separation of solid particles and droplets contained in gas is called dust collection in general terms. Particles in gas are called smoke, fog, dust, mist or fume, however these are not clearly classified. Generally, a solid particle is called dust and a liquid particle is called mist. In particular, fine solid particle generated by vapor condensation, which is less than 1 μm , is called fume. Various methods for dust collection have been tried and used practically. If the typical methods are classified depending on their collection mechanisms, gravity precipitation (gravity settling chamber, multistage settling chamber), inertia separation (baffle chamber, louver chamber), centrifugal separation (cyclone, multi-clone, double clone, cyclone scrubber), filtering dust collection (bag filter, fiber packed bed), cleaning dust collection (venturi scrubber, spray tower, jet scrubber, Teisen washer), and electrostatic precipitator (Cottrell, two-stage) are picked up. However, it is sometimes difficult to classify clearly because, in the wet type cyclone for example, its centrifugal force using cyclone incorporates a cleaning spray, and in types using gravity or inertia, some mechanisms are combined.

4.2.1 Gravity Type Dust Collector

In this equipment, dusty gas is introduced to the air and dust is made to drop by its own gravity and be separated. This is a simple structure with an empty room and dust discharge section. After entering the settling chamber and decelerating to 1 through 2 m/s, dust loses inertia and is settled down. From the theory of dust settling in an empty room, the larger the distance of advancing in the room and the smaller the room height, the smaller the dust that can be separated. However, because the installation area increases as the settling chamber length is larger, actually the settling height is reduced and the some settling chambers are arranged in multistages. This is called a multistage settling chamber (forward type). The forward type shown in Fig.4.24 can be applied to dust up to 20 microns. This equipment is easy to handle and cheap, and pressure loss is as small as about 10 mm H₂O. Thus this is suitable for a pre-duster (primary dust collector) for processing gas containing a large amount of dust.

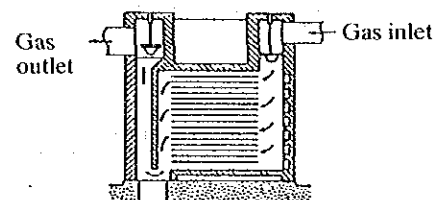


Fig. 4.24 Forward Type Dust Collector

4.2.2 Inertia Type Dust Collector

The inertia type dust collector separates and collects particles by their inertia force by making dusty gas collide against the baffle or changing the flow direction of the gas stream rapidly. From the viewpoint of use of inertia force, dust collectors by centrifugal force, cleaning and the sacked bed type belong to inertia dust collectors, this section refers to only relatively simple dust collecting methods by inertia force (or gravity). Fig.4.25 outlines the equipment.

The type (a) is a collision type which enhances the separation effect by converted flow. The louver type (d) utilizes the effect of the reversal type. In this type, dusty gas is introduced to a cylinder narrowing toward the end provided with obliquely backward facing slits and dust is advanced forward by inertia to introduce to the dust collection box at the end. To make gas speed constant near the slit inlet, it is necessary to provide a louver pipe with an appropriate taper and an appropriate number of pipes are arranged in parallel corresponding to the amount of processing gas. Whether the function of the inertia dust collector operates properly can be judged according to the following items.

- ① In the collision type, high speed gas just before collision and low speed gas at the outlet of the equipment generally makes less carry over of separated dust and high efficiency of dust collection.
- ② In the reversal type, the smaller the curvature radius of gas turned in direction, the finer the dust that can be separated and collected.
- ③ The more frequently the direction of dusty gas flow is changed, the greater the pressure loss becomes, however the higher the dust collection rate becomes.
- ④ The dust hopper is required to be provided with the configuration preventing separated dust from being accompanied by gas flow easily and a sufficient volume considering any trouble with the discharge device.

A high dust collection rate cannot be expected for any type mentioned here. These are suitable for dust of over 20μ and mist of over 2μ and effective as a pre-duster. They are used under a flow speed of 2 m/s through 30 m/s and the pressure loss is less than 100 mm H_2O .

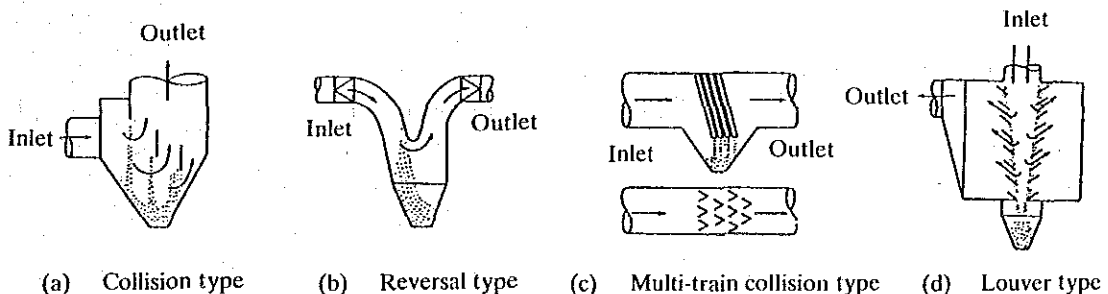


Fig. 4.25 Types of Inertia Dust Collectors

4.2.3 Centrifugal Type Dust Collector

This separates dust by centrifugal force gained by swirling dusty gas. Use of centrifugal force can obtain a settling speed (transverse direction) several hundreds through several thousands times the gravity and an excellent dust collecting effect can be expected. The ratio of centrifugal force to gravity is called centrifugal force effect and can be obtained from the equation mentioned below.

$$Z = V^2 / rg \dots\dots\dots (4-1)$$

Where: r is rotation radius (m), v is rotation peripheral velocity (m/s) and g is gravitation acceleration (m/s²). The value obtained here enables evaluation of the performance of centrifugal force dust collection. Because z increases if r decreases as evident in the equation 4-1, a relatively small cyclone exerts an excellent performance so that it can separate up to several μm.

(1) Cyclone

The cyclone is typical equipment and the principle is shown in Fig.4.26. Dusty gas is blown in tangentially at the speed of 10 m/s through 20 m/s from the top of the cylinder. This gas goes down to the conical section swirling along the inside wall, turns into a stream rising in the center and finally goes out through the discharge pipe on the top of the cylinder. When rough dust swirls inside, it collides against the wall of the cylinder due to a large centrifugal force and settles in the dust collection box. The wall surface is likely to be worn by this centrifugal force, therefore an expensive material is required for the wall. Appropriate grain diameter of dust to which this equipment is applicable is 10 μm to 200 μm and pressure loss is 100 mm H₂O to 200 mm H₂O, higher than other equipment.

(2) Multi-cyclone scrubber

As shown in Fig.4.27, the gas paths in the cylinders of small cyclones arranged in parallel are provided with guide vanes to give a centrifugal force. Consequently a large amount of gas can be processed and dust up to several μ can be collected. This belongs to the high-performance centrifugal separator and its dust collection rate is 70% through 95%.

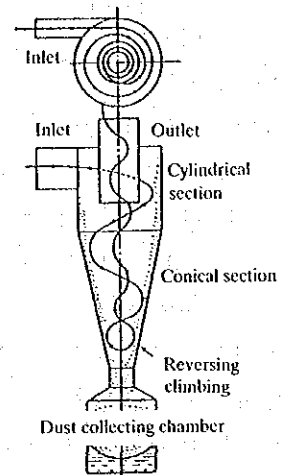


Fig. 4.26 Cyclone

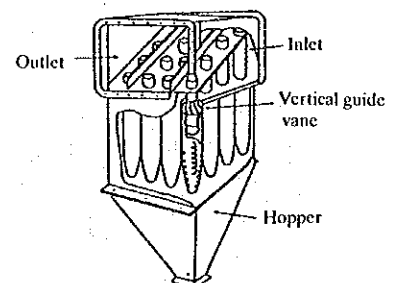


Fig. 4.27 Multi-cyclone

(3) Cyclone scrubber

This type intends to raise the dust collection rate by spraying water to dusty gas and Fig.4-28 shows the schematic view. This can be also classified as a cleaning dust collector. Due to simple mechanisms and excellent performance, various modified types are presented. If dust is deposited in the hopper (conical section), blow-up occurs so that the dust collection rate is reduced. To eliminate this phenomenon, the following modified types are invented: double clone whose dust collecting section is provided with another auxiliary cyclone in series, blow-down type extracting gas from the dust collecting section through a filter or small cyclone and the Fangton-Gellen type whose cylindrical section is provided with a reserved separating chamber to prevent dust from scattering near the gas outlet to raise the dust collection rate.

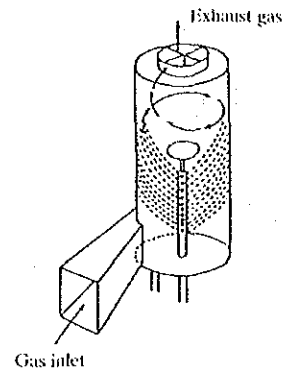


Fig. 4.28 Cyclone Scrubber

4.2.4 Filter Type Dust Collector

This equipment filters dusty gas by means of a filter to separate dust. The filtering materials are woven cloth (or paper) and packed bed (mainly glass fiber or sometimes sand or coal). Because the dust collecting mechanisms of both are different, it is necessary to consider them separately. The air filter of the packed bed type is limited to the case that the dust concentration of inlet is very low, for example, for air regulation. In the filter type dust collection using a filtering material, the dust layer deposited on the surface of a thin filtering material such as cloth or paper is used for filtering. This is called surface filtering. A typical surface filter type is a bag filter. Fig.4.29 shows the filtering mechanism. First, dust adheres to a filtering cloth and is separated, so that the so-called primary layer is formed. Until then, the dust collection rate is low. However, once the primary layer is formed in several seconds through several minutes, the dust layer itself can catch fine dust of about $1 \mu\text{m}$, so that the dust collection rate exceeds 99%. Because pressure loss increases gradually, the dust layer is removed but the primary layer is left so as to maintain the dust collection rate. In the conventional bag filter (Fig.4.30), cylindrical bags, 10 cm to 50 cm in diameter, 1 m to 10 m long, are hung in parallel with their bottoms up and gas is fed inside from the bottom. The dust layer adhering to the bag is thrown off at an appropriate interval of time. This mechanism is so important that the performance of the equipment is affected. Fig.4.31 shows the typical four types of de-

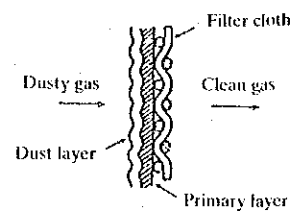


Fig. 4.29 Mechanism of Filtering Effect on Filtering Cloth

dusting methods.

The type ① is the conventional mechanical vibration type and recently, the reverse jet types shown in ③ and ④ have become prevalent. This type enables continuous filtering operation and has an advantage in that no additional filtering chamber is required. Although the gas flow speed on the filtering surface differs depending on the dust grain diameter. Generally it is 0.3 cm/s to 10 cm/s. Pressure loss is 100 mm H₂O to 150 mm H₂O and the equipment cost is the most expensive next to the electro electrostatic precipitator. This is not suitable for high temperature gas of over 100°C (the recent glass wool filtering cloth can withstand up to about 300°C.) and wet gas treatment. A blow-off sometimes occurs from a local damage due to the abrasion of filtering cloth. Although the heat resistance, alkali resistance, hygroscopicity and mechanical strength of the filtering cloth differ depending on the type of filtering material, selection corresponding to the characteristic of the gas to be treated is required.

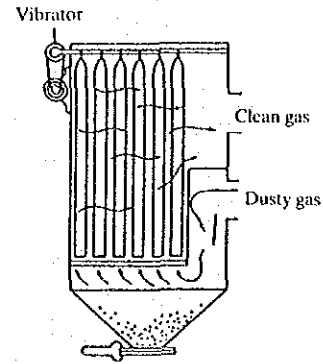


Fig.4.30 Bag Filter

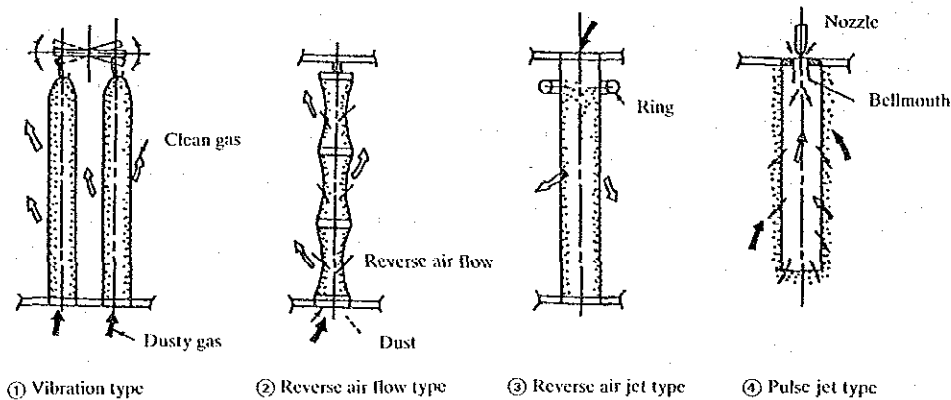


Fig. 4.31 Methods for Dedusting

4.2.5 Cleaning Type Dust Collector

This method catches dust in cleaning water and separates it by making it collide against or contact with droplets or liquid film. This equipment is called a scrubber. The major separating mechanisms are ① Collision and adherence of fine dust to droplets and liquid film by inertia. ② Adherence of fine dust to droplets and liquid film by diffusion ③ Increasing cohesion of particles by increasing moisture ④ Condensation of vapor with dust as the core and ⑤ Adherence of dust to air bubbles. According to this method, the equipment cost is relatively cheap, and depending on the type, dust up to 0.1 μm can be collected at a high collection rate, and it is possible to remove harmful gas such as sulfuric oxide by use of alkali solution. However, the greatest disadvantage is

that a large amount of water is required (although the amount differs depending on the type, 0.05 liters is required per 1 liter of gas) and the operation to treat discharged fluid further shall be necessary. Thus the costs of thickener and other water treatment equipment shall be added. In the case of corrosive gas, corrosion and erosion become a problem. Pressure loss is generally high, especially in the case of venturi, it rises as high as 850 mm H₂O. The scrubber is largely classified into the following three types.

(1) Water pool type

In this type, a specified amount of water or other liquid is always pooled so that the purpose can be attained by less water. To feed liquid, no pressure is required. This type includes the packed column type holding spherical material on a porous plate and the converted flow type scrubber as shown in Fig.4-32. In the latter case, when dusty gas enters into water at high speed and is converted through water while dissipated like bubbles, dust is caught. Pressure loss is also high.

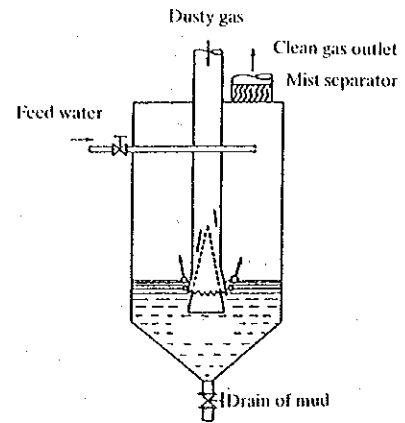


Fig. 4.32 Converted Flow Type Scrubber

(2) Pressurization type

According to this method, pressurized water is injected to catch dust through collision or diffusion. This type includes the venturi scrubber (Fig.4.33), jet scrubber (Fig.4.34) and cleaning tower (Fig.4.35).

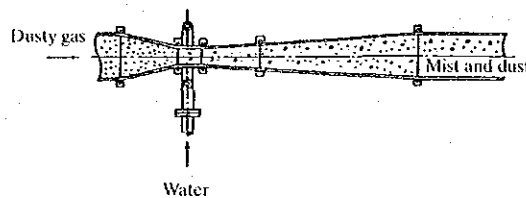


Fig. 4.33 Venturi Scrubber

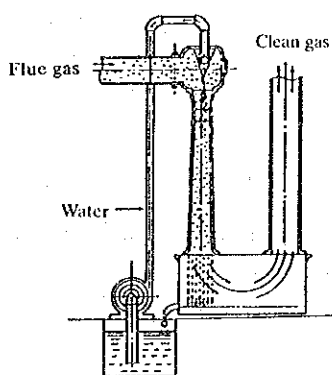


Fig. 4.34 Jet Scrubber

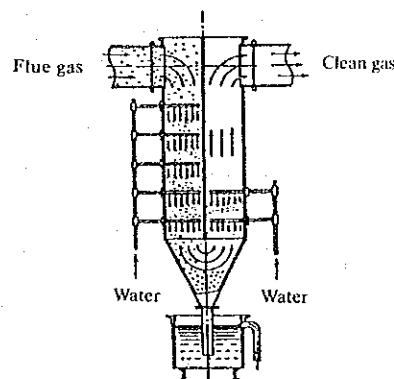


Fig. 4.35 Cleaning Tower

The venturi type is the most excellent in efficiency. By inserting a venturi pipe into the gas suction part of the cyclone, gas speed at the throat is raised to as high as 50 m/s to 100 m/s. By pouring cleaning liquid with liquid/gas ratio of 0.5 to 1.5 liter/m³ through the nozzle, liquid is atomized by a high-speed air stream, comes into a contact with gas due to a violent turbulence in the expansion tube and is separated in the cyclone. The disadvantage of this type is that pressure loss is as large as 400 mm H₂O to 850 mm H₂O, however a high dust collection rate can be expected. Recently in a high-pressure furnace in particular, a venturi of about 2,000 mm H₂O is often used. This pressurization type uses supernatant liquid separated by thickener or strainer. It is necessary to take precautions against plugging of the pressurization nozzle.

(3) Rotation type

The type distributing cleaning water by mechanical rotation of an impeller is generally called the rotation type, and the Teisen washer and rotoclone belong to this type. The Teisen washer provides dusty gas passing between the multi guide vanes and rotating bar vanes with a violent turbulence by shearing force due to rotation movement. On the other hand, by spraying water radially from the center by means of a centrifugal blower, dust in gas is made to contact with and be caught by the water. The advantage is that pressure can be raised to 100 mm H₂O to 200 mm H₂O.

4.2.6 Electrostatic Precipitator

In the electrostatic precipitator, corona discharge is generated by DC high voltage to charge dust in gas (discharging electrode), and by passing these charged particles through electric field with electric energy, dust is separated from gas by catching it with an electrostatic (dust collecting mechanism). As compared with other dust collectors, this type ensures a high dust collection rate and can collect even submicron particles of less than 1 μm.

The electrode type is classified into the balanced flat plate type and the cylinder type (See Fig.4-36) and usually, the negative pole is a discharging electrode and the positive pole is grounded to be a dust collecting electrode. Fig.4-37 shows the balanced flat plate type and the circle in the center indicates a high pressure discharging electrode. When a voltage of several tens thousands volts is applied on this discharging electrode, a corona discharge occurs between both electrodes followed by a spark, so that air insulation is destroyed. Of generated ions with positive and negative signs, a positive ion with a sign different from the discharging electrode loses its charge at the discharging electrode and negative ion adheres to the gas molecule or dust so that it is col-

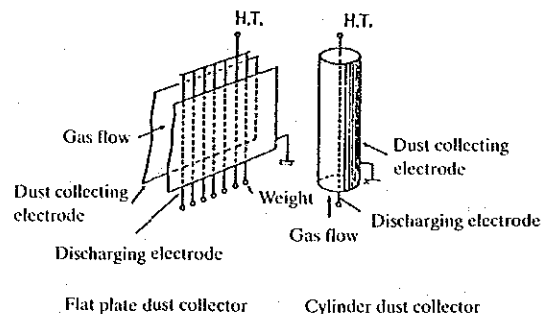


Fig. 4.36 Single-stage Electrostatic Precipitator

lected to the dust collecting electrode by coulomb force.

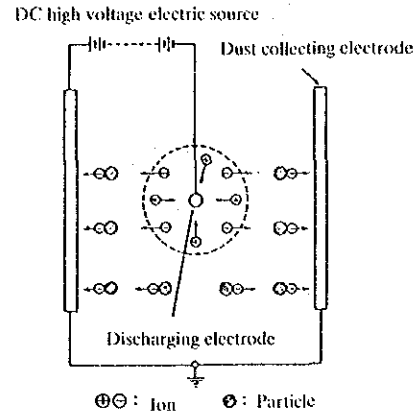


Fig. 4.37 Mechanism of Electrostatic Precipitator

(1) Single-stage type and double-stage type

As shown in Fig.4.38, the electrostatic precipitator is classified into the single-stage type and the double-stage type depending on the charging type.

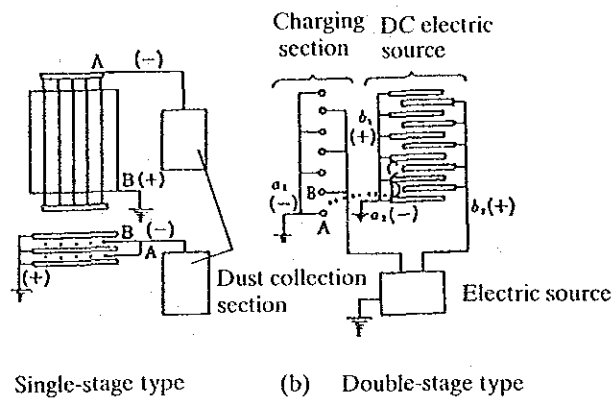


Fig. 4.38 Classification of Electrostatic Precipitator by Charging Type

The single-stage type is employed widely for industrial use, and the charging section and the dust collecting section exist in the same electric field. Although the single-stage is very effective for rescattering of dust because charging of scattered dust and dust collection are conducted repeatedly, reverse ionization, which occurs if the apparent electric resistance of dust is abnormally high, is unavoidable. On the other hand, in the double-stage type, the charging section and dust collecting section are separated. This type is employed for an air cleaner used in the condition with fine dust in very low concentration and as electrostatic coherer used for pretreatment of flue gas in the condition with fine dust in relatively low concentration. In this case, although no reverse ionization occurs, dust rescattered when the dust collecting electrode is patted is accompanied, therefore usually the secondary dust collector is required on the subsequent step.

(2) Wet type and dry type

The way to clean off dust adhering to the electrode of the electrostatic precipitator is divided

into the type giving mechanical impact to the electrode and the water washing type. The former is called the dry type electrostatic precipitator and the latter is called the wet type electrostatic precipitator. In the case of the dry type, when the electrode is mechanically patted, dust is rescattered, and the dust rescattering which occurs when the apparent electric resistivity is not suitable for the action of the electrostatic precipitator may be accompanied. The wet type has no problem of rescattering since the water film down flow covers the electrode surface.

(3) Dust collection rate of electrostatic precipitator

The dust collection rate of the electrostatic precipitator is generally provided by the equation shown below.

$$\eta = 1 - \exp\left(-\frac{\omega A}{Q}\right) \dots\dots\dots (4-2)$$

Where:

- η : Dust collection rate
- ω : Moving speed of dust (cm/s)
- A: Effective dust collecting area (cm²)
- Q: Processing gas amount (cm³/s)

To increase the dust collection rate, it is necessary to increase the moving speed " ω " of the dust particle and to enlarge the effective dust collecting area per processing gas amount (A/Q). What affects the moving speed " ω " most is the strength of the electric field in charging and the dust collecting space. The effective dust collecting area per processing gas amount (A/Q) increases to raise the dust collection rate as the charging time increases or in another word, the equipment is enlarged.

(4) Apparent electric resistivity of dust and dust collection rate

What affects the discharge characteristic of the electrostatic precipitator most and the dust collection rate is the apparent electric resistivity of dust. Generally, electric resistivity refers to the constant determined by material type. The electric resistivity of a material is obtained by measuring the electric resistance of material of a specified form. This resistance is called the inherent electric resistivity of material. Namely, the electric resistivity of material is obtained by converting to such resistance of a specified form. Fig.4.39 shows the apparent electric resistivity, the dust collection rate and discharge current under gas temperature and humidity at the processing time.

1) Case of less than 10⁴ ohm·cm (rescattering range)

If the apparent electric resistivity of dust is less than 10⁴ ohm·cm, as soon as charged dust adheres to the collecting electrode as shown in Fig.4.40, the charge is discharged and neutralized and jumps into space. This turns to charged dust immediately, adheres to the collecting electrode,

releases its charge and returns to space. This action repeats. Generally, this is called the skip phenomenon or abnormal scattering.

2) Case of $10^4 - 5 \times 10^{10}$ ohm-cm (normal range)

If the apparent electric resistivity of dust is about $10^4 - 5 \times 10^{10}$ ohm-cm, electric neutralization of charged dust is performed at an appropriate speed, therefore an ideal dust collection is performed.

3) Case of 5×10^{10} through 10^{11} ohm-cm (frequent spark range)

If the apparent electric resistivity of dust exceeds 5×10^{10} ohm-cm, electric neutralization of charged dust adhering to the dust collecting electrode is delayed so that, as shown in Fig.4-41, an electric field is formed in the dust layer adhering to the surface of the dust collecting electrode, and consequently the corona generating voltage of the discharge electrode is reduced by it. If the limit of the insulation destructive electric field strength of the dust layer is exceeded, a positive corona occurs from the dust collecting electrode. (This phenomenon is called reverse electrolytic dissociation and the dust collecting rate is lowered under this condition.

This frequent spark range is also called the first stage of electrolytic dissociation.

4) Case of more than $10^{12} \Omega \cdot \text{cm}$ (reverse electrolytic dissociation range)

If the apparent electric resistivity of dust is more than $10^{12} \Omega \cdot \text{cm}$, the sparking discharge disappears and the electric charge is stable. Thus, discharging current is released so largely that insulation destruction occurs over all the surfaces of the dust layer and a positive corona with phosphorescence generates from all the surfaces of the dust collecting electrode. (See Fig. 4-42)

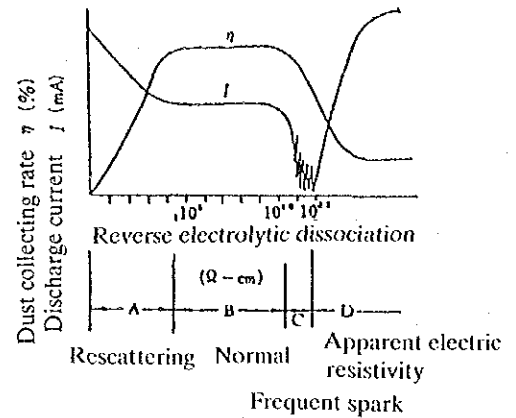


Fig.4.39 Apparent Electric Resistivity of Dust and Dust Collection Rate

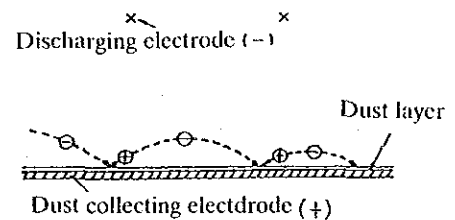


Fig. 4.40 Abnormal Phenomenon of Rescattering

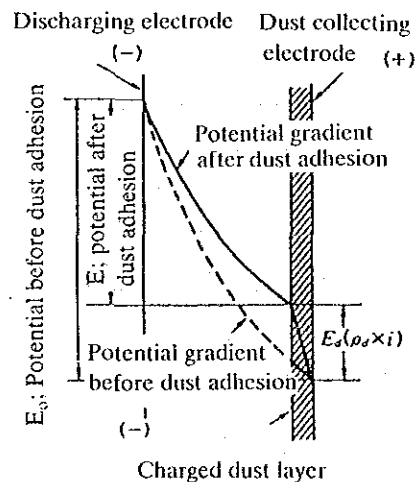


Fig. 4-41 Type of Electric Field by Negative Charged Dust

If this reverse electrolytic dissociation occurs, apparently the charge is stable and a large amount of discharging current flows. Most part of this current is positive corona current, acting as reverse for dust collection thereby reducing dust collection rate eminently. As countermeasure against reverse electrolytic dissociation, usually, the apparent electric resistivity of dust is reduced by adjusting humidity of processing gas. To adjust the humidity, SO_3 or water is poured into processing gas.

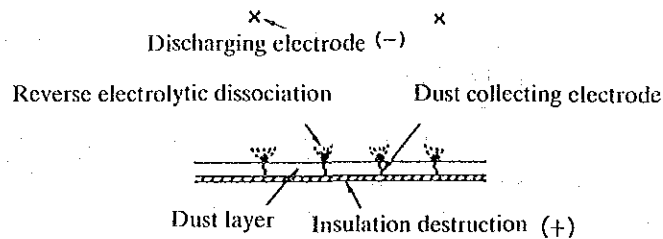


Fig. 4-42 Phenomenon of Reverse Electrolytic dissociation

4.2.7 Precautions on Selection of Equipment

All the dust collectors have advantages and disadvantages and no universal type exists. In particular, dust whose concentration is high and whose grain diameter distribution is wide cannot be collected completely by one type of equipment. Thus, two types of systems are often combined. Another popular method is to place a simple separator ahead to improve the dust collection rate. The combination must be considered depending on the situation. The dust collector consists of the hood, nozzle, duct, separator, blower and discharge dust processing device. The role of the hood is great in the dust collector for improving the work environment and the open type furnace (electric furnace). Over half of the troubles caused during dust collector operation concerned the blower, therefore it is necessary to select the type and material of the blower and fan considering adhering of dust on the blade and the action of harmful gas content accompanied by water condensation. Because the auxiliary portion of the dust collector may determine its performance depending on the situation, upon the selection, consider the dust and gas condition, and the characteristic and maintenance of various equipment. Table 4-7 shows the performance comparison of equipment.

Table 4-7 Practical Comparison of Various Dust Collectors

Class	Type	Diameter of grain to be handled [μm]	Pressure loss [mm Aq]	Dust collection rate [%]	Equipment cost	Operating cost
Gravity type dust collector	Sedimentation chamber	1000~20	10~15	40~60	Small figure	Low level
Inertia force type dust collector	Louver type	100~20	30~80	50~70	Small figure	Low level
Centrifugal force type dust collector	Cyclone type	100~5	100~200	70~95	Medium figure	Medium level
Cleaning type dust collector	Venturi scrubber type	100~ 0.1	400~850	80~95	Medium figure	High level
Filter type dust collector	Bag filter	20~ 0.1	100~200	90~99	Medium figure	More than medium level
Electrostatic precipitator		20~ 0.05	10~20	80~99.9	Large figure	Low to medium level

5. Economic, Industrial and Energy Policies of Thailand and Their Effects on the Environment

5.1 Economic and Industrial Policy Trends

Thailand was an agricultural country until 30 years ago, but significant changes began to take place in Thailand's industries around 1960. The agricultural sector began to produce crops other than rice such as maize, sugar cane and cassava, and the manufacturing sector began to produce a variety of consumer goods with the help of various protective measures by the government. The pace of agricultural diversification and industrialization accelerated in the 1970's. In 1950, agriculture, forestry and fishery outputs accounted for 46% of Thailand's nominal gross domestic product (GDP), far outstripping the outputs of the manufacturing sector. The gap between the shares of GDP by agriculture, forestry and the fishery sectors and the manufacturing sector narrowed rapidly since 1980, and the GDP shares in 1983 were 20% for agriculture, forestry and fishery and 21% for the manufacturing sector. By 1987, the manufacturing sector far outstripped by the agriculture, fishery and forestry sectors, the GDP share of the manufacturing sector being 24% and that of the agriculture, fishery and forestry sectors, 16%. In the foreign trade area, the ratio of the exports to the GDP reached 29% in 1987, largely due to Thailand's government sustaining its open economy policy for many years. As the amount of exports increased, the mix of exported products broadened from primarily food products and raw materials to include industrial goods, and the percentage of industrial goods, such as ICs and textile products, rose to 21% of the total export value in 1987. This clearly indicates that Thailand's export structure is shifting from agricultural and fishery goods to industrial manufactured goods.

Helped by the growth of the agriculture, forestry and fishery sectors and the manufacturing sector, Thailand's First National Economic and Social Development Plan, started in 1961, through the latest Sixth National Economic and Social Development Plan have produced excellent economic growth for the country.

Plan	Period	Economic Growth
First	1961-1966	8.1%
Second	1967-1971	7.2%
Third	1972-1976	6.2%
Fourth	1977-1981	7.3%
Fifth	1982-1986	4.9%
Sixth	1987-1991	5.1% (plan)

The Thailand economy expanded favorably with an average annual economic growth rate of 6.7% in the 25 years from inception of the First National Economic and Social Development Plan in 1961 through the end of the Fifth National Economic and Social Development Plan in 1986, but a number of problems recently have begun to surface. The rapid increase of population in the 1950's and into the 1960's resulted in a rapid increase of job seekers since early 1980's. Because the agricultural sector no longer has the ability to absorb these new workers, unemployment has in-

creased in cities, exacerbating social and economic imbalance. Thailand's forestry sector has been diminishing ever since the World War II because of nonstopped exploitation of forestry resources for farming and the expansion of farmland and residential land. Forestry land accounted for 66% of the total land in 1958, but the ratio has dropped to only 25% in 1988, indicating the rapid deforestation of Thailand.

The growth of the Thailand economy supported from both agricultural and industrial sectors made large impacts on the living conditions of the Thailand citizens. Deterioration of living conditions in the large cities and environmental pollution by industrial wastes in the suburbs of large cities have become especially serious problems. Recognizing these problems, the government officials responsible for formulation and implementation of the Sixth National Economic and Social Development Plan and subsequent economic policies have begun to stress the importance of "quality improvement," "parity of central and regional economies" and "improvement of economic efficiency" over the quantitative expansion of economy. In addition to this priority shift, solving the government budget and international balance of payment problems caused by the rapid economic growth of the past has become a central issue for the Thailand government. The key policy goals of the Thailand government are summarized below.

(1) Improvement of the quality of economy

- ① Carefully plan and administer economic policies and assign high priority to improving the international balance of payments.
- ② Develop industries that will expand employment instead of industries that will simply contribute to economic growth numbers.
- ③ Develop industries that are tailored to local needs rather than pushing for development of heavy manufacturing and chemical industries.
- ④ Give priority to smaller and medium scale projects over large scale projects.
- ⑤ Work toward improving the lives of the low income population.
- ⑥ Diversify agricultural and industrial productions to raise the income level of farmers and to create new jobs.

(2) Utilization of private capital

- ① Privatize government-run institutions or inject private capital into such institutions.
- ② Transform existing nationally owned enterprises into more efficiently managed and business-like operations.
- ③ Achieve a fair distribution of burdens on city development and redevelopment among the central government, local governments, nationally owned enterprises and private enterprises.

(3) Implementation of a regional diversification policy

- ① Work toward dispersion of the population toward regional areas.
- ② Redevelop Bangkok and eleven other major cities.

- ③ Emphasize traffic, water supply, housing and flood control as basic services for cities.
- (4) Implementation of eastern coastal region development program
 - ① Work toward effective utilization of natural gas and other domestic resources.
 - ② Enable relocation of factories from Bangkok.
 - ③ Shift from consumer goods production to heavy manufacturing and chemical production.
 - ④ Develop export oriented industries.

5.2 Energy Policy Trends

Final-form energy demands in Thailand grew from 1960 through just before the first oil crisis of 1973 at an annual rate of approximately 8%. The annual rate of increase dropped slightly to 6% during the period from 1973 to 1980, but the demand for commercial energy increased at an annual rate of 7% from 1980 to 1988. Table 5-1 shows the breakdown of energy supplied by sources. The total supply of primary energy in Thailand in 1988 was 33 million tons of crude oil equivalent (see Table 5-2).

Table 5-1 Energy Supply by Sources

Year	Oil	Wood, Charcoal	Natural gas	Lignite, Coal	Hydro-power	Rice hulls, Bagasse	Total
1985	36%	25%	17%	8%	4%	10%	100%
1986	37%	24%	15%	8%	6%	10%	100%
1987	44%	19%	17%	8%	4%	8%	100%

Wood and charcoal, which are renewable energy sources, are on the decline as the government is moving towards limiting logging operations to protect the country's forests. Demands for bagasse and rice hulls have hit the plateau. Therefore, Thailand's government energy development and utilization policies are being concentrated for natural gas, lignite and petroleum. From the economic policies and energy situation described above, the following policies in the energy area by the Thailand government are desired:

Table 5-2 Supply of Primary Energies in Thailand

(Unit: 1000 toe (tonn oil equivalence))

	1980	1981	1982	1983	1984	1985	1986	1987	1988	88/83	88 Proportions
Primary energy production											
Lignite	408	461	608	577	667	1,401	1,508	1,932	2,049	28.8	9.8
Crude oil	14	15	15	328	737	1,083	1,058	894	1,017	25.4	4.9
Condensate, natural gas		324	1,410	1,697	2,475	3,899	3,787	5,080	6,015	28.8	28.9
Hydropower	282	659	850	811	904	818	1,230	903	837	0.6	4.0
Renewable energy	10,285	10,678	11,158	10,912	11,061	11,246	11,149	11,058	10,890	0.0	52.3
Subtotal	10,989	12,137	14,041	14,325	15,844	18,447	18,732	19,867	20,808	7.8	100.0
Energy imports											
Coal	60	43	102	109	144	213	141	197	240	17.1	2.0
Crude oil, petroleum products	11,886	10,617	9,274	10,593	10,386	9,118	9,329	11,126	11,835	2.2	97.6
Electric power	65	63	64	60	61	62	64	35	37	-9.2	0.3
Renewable energy	1	2	3	5	9	8	9	10	11	17.1	0.1
Subtotal	12,012	10,725	9,443	10,767	10,600	9,401	9,543	11,368	12,123	2.4	100.0
Total primary energy supply	22,534	23,002	23,764	24,870	26,330	27,401	28,089	31,327	33,339	6.0	
Energy exports											
Coal and lignite	1	1	1	1							
Condensate				63	126	403	493	445	676		
Petroleum products	14	1	3	2	3	37	76	29			
Electric power	1	1	1	2	2	2	1	1			
Renewable energy	27	35	44	48	38	32	26	37	15		
Subtotal	43	38	49	116	169	474	596	513	693		
Total—domestic	22,491	22,964	23,715	24,754	26,161	26,927	27,493	30,814	32,646	5.7	
Ratio of domestic production (%)	48.8	52.8	59.1	57.6	60.2	67.3	66.7	63.4	62.4		

Source: NEA "Thailand Energy Situation 1988"

(1) Diversification of domestic energy sources

Importation of petroleum derived fuels is still high, and consumption of commercial energies will increase even further if the Thailand economy continues to grow at an annual rate of 6%. Therefore, explorations for crude oil, natural gas and lignite must be continued. Electric power generating plants are the largest users of natural gas, but glass and cement manufacturing plants are already using natural gas, and further expansion of natural gas usage as industrial fuel and raw material must be encouraged.

Lignite is mined in Mae Mo and Li in the northern region and Krabi in the southern region, but it is not suitable for long-distance transportation and therefore cannot be used in its original form in and around Bangkok. Lignite is currently used to fuel electric power generating plants near where it is mined, but use of this abundantly available and cheap energy source must be broadened somehow. To develop domestic crude oil sources, the Thailand government is working on a plan to enable speedy development of oil fields in the Gulf of Thailand by private oil companies and by the governments of neighboring countries, and early completion of this planned work is required. Some of the petroleum products currently used in Thailand are imported, and importation of some petroleum products is expected to continue because domestic petroleum refining operations cannot avoid the imbalance between demand and supply from time to time. In order to stabilize the cost of imported petroleum energy, the government must work on diversifying the sources of imported crude oil and petroleum products.

(2) Correction of the energy pricing structure

The Thailand government must decontrol the energy prices in order to maintain international competitiveness, and must consider the limitation in the efficiency with which government agencies can operate. Specifically, the government currently has monopoly on sales of domestically produced natural gas and petroleum, but the private sector should be allowed to sell these products freely in the future. Also, natural gas producers and users should be allowed to negotiate the prices. The government should abstain from giving special incentives to selected energy products and allow the force of free market competition to determine the supply and demand of all types of energy.

(3) Raising the energy efficiency

Chronic traffic congestion in Bangkok is a major cause of energy loss, and public transportation systems should be reorganized and expanded to solve the traffic congestion problem. Buses and many types of taxi services are available in Bangkok today, and the very existence of this many public transportation services is a cause of traffic congestion. Reorganization of bus routes and improvement of city streets will not be enough to solve the traffic congestion problem. Building of a rail system, subway system, monorail system, etc. is essential to fundamentally solve the chronic traffic congestion problem in Bangkok. Some of the actions currently proposed to alleviate the traffic problem are "the elimination of dead-end streets," "construction of roadways connecting the center of the city and the suburbs," "construction of a new canal," "construction of access roads for a more efficient use of land around Bangkok," "improving the quality of public transportation systems," and "construction of main throughways for developing new cities in the suburb" (from "Planning for Traffic Improvement by the Bangkok Metropolitan Region Development Board).

Energy saving centers should be established to promote saving energy at homes and in factories. These centers should provide technical training on energy saving means, conduct research on saving energy and provide instructions for proper use of and making improvements on combustion apparatuses used by local residents. The centers should also provide low-interest loans to promote energy consumption reduction by factories. The government should also offer tax incentives for installation of energy-efficient equipment and machinery in factories.

(4) Local energy development

Logging for use as fuel by local residents is the cause of forest destruction in the north-eastern region, so that the government must quickly make available fuels that can replace fire wood.

5.3 Energy Demands and Supply

5.3.1 Demands for Energy

A breakdown of final energy demands by user groups were as follows in 1987: transportation 37%; commercial and residential 30%; mining and manufacturing 27%; agriculture 4%; others 2%. (See Table 5.3.) The demands for commercial energy in Thailand increased at an annual rate of 7%

from 1980 to 1988, but the annual growth rate for the total primary energy in the same period was 4.7%. The difference comes from a nongrowth of demands for renewable energy sources such as fire wood, charcoal and bagasse, which account for one half of the primary energy. The demands for these energy sources are not expected to increase in the future, and it is expected that commercial energy will slowly become the predominant energy source in Thailand. The Thailand government's official view on the energy demand situation is as described below.

The five-year Sixth National Economic and Social Development Plan (1987 to 1991) assumes a 4.2% annual growth of energy demands, but the growth rate is expected to drop to about 3.1% in the five years after 1992. Table 5-4 shows the demand growth rates for commercial and renewable energies.

Table 5-3 Energy Consumption in Thailand

(Unit: 1,000 toe petroleum equivalent)

1985 Year	Commercial energy											Renewable energy					Grand total		
	Coal	Lignite	Petroleum								Natural gas	Electric power	Commercial energy total	Wood	Charcoal	Rice hulls		Bagasse	Renewable energy total
			LPG	Gasoline	Jet fuel	Kerosene	High-speed diesel	Low-speed diesel	Fuel oil	Sub-total									
Agriculture			3	49		2	772	2		3	836		5	841					841
Miner. industry				1		1	57			2	71			74					74
Manufacturing industry	190	233	84	8		38	158	27	1,099	13	1,414	178	792	2,807	501	583	1,219	2,383	5,191
Construction				2			109				123			125					125
Consumer goods, commercial			341			82	1		5	429			895	1,324	2,291	2,138	247	4,679	6,003
Traffic			219			7	3,467	32	165	9	6,342			6,342					6,342
Others			1	1,426	1,012	1	111	1			193		15	208					208
Total consumption	190	233	668	1,556	1,012	126	4,675	69	1,307	9,413	178	1,707	11,231	2,875	2,138	839	1,219	7,062	18,763

(Unit: 1,000 toe petroleum equivalent)

1986 Year	Commercial energy											Renewable energy					Grand total		
	Coal	Lignite	Petroleum								Natural gas	Electric power	Commercial energy total	Wood	Charcoal	Rice hulls		Bagasse	Renewable energy total
			LPG	Gasoline	Jet fuel	Kerosene	High-speed diesel	Low-speed diesel	Fuel oil	Sub-total									
Agriculture			3	57		1	812	2		3	875		5	881					881
Miner. industry				2			29			19	53			53					53
Manufacturing industry	141	323	84	7		38	154	20	1,145	20	1,414	87	866	2,858	572	564	1,270	2,386	5,244
Construction				2			101				123			123					123
Consumer goods, commercial			472			43	1		11	509			992	1,501	2,318	2,100	254	4,670	6,171
Traffic			194			2	3,647	41	241	5	6,805			6,805					6,805
Others			1	1,557	1,120	2	129				211		15	226					226
Total consumption	141	323	704	1,691	1,120	87	4,874	60	1,453	10,018	87	1,878	12,447	2,885	2,103	838	1,270	7,056	19,503

(Unit: 1,000 toe petroleum equivalent)

1987 Year	Commercial energy											Renewable energy					Grand total		
	Coal	Lignite	Petroleum								Natural gas	Electric power	Commercial energy total	Wood	Charcoal	Rice hulls		Bagasse	Renewable energy total
			LPG	Gasoline	Jet fuel	Kerosene	High-speed diesel	Low-speed diesel	Fuel oil	Sub-total									
Agriculture			3	49		1	775	1		3	830		5	835					835
Miner. industry				1			35			13	49			49					49
Manufacturing industry	174	478	78	8		37	151	13	1,311	14	1,598	40	964	3,254	565	527	1,224	2,316	5,570
Construction				1			95				111			111					111
Consumer goods, commercial			503			64	1		17	385			1,136	1,734	2,270	2,103	261	4,634	6,355
Traffic			166			1	4,301	64	241	5	7,883			7,883					7,883
Others			1	1,811	1,218	1	91				171		16	187					187
Total consumption	174	478	751	1,935	1,218	105	5,451	87	1,667	11,207	40	2,321	14,020	2,835	2,103	785	1,224	6,950	20,970

Table 5-4 Energy Demand Growth Rates (%)

	Sixth Plan	Next 5 Years
Commercial energy	5.9%	4.1%
Renewable energy	0.8%	0.1%
Total	4.2%	3.1%

Source: "Energy Development Plan during the Period of the Sixth National Economic and Social Development Plan" 1986 by NESDB

5.3.2 Energy Supply

The energy supply structure in Thailand as shown in Table 5-5 is changing in two important areas. One is the reduction of reliance on imported commercial energy, and the other is shifting from renewable energy to commercial energy. As described earlier, more than 90% of commercial energy was imported in 1980, but subsequent development of domestic energy sources (natural gas, crude oil, lignite, etc.) has reduced reliance on imported commercial energy to less than 60% today. Renewable energy accounted for 46% of total energy supply in 1980, but the ratio dropped to 33% in 1988. These two trends are expected to continue in the area of energy supply in Thailand, and the Thailand government is promoting development of domestic energy sources and increased utilization of commercial energy. While promoting development of domestic natural gas and oil fields and lignite mines, the government is promoting diversification of natural gas and lignite consumption which has been stagnant in the recent years. Forecast of commercial energy supply situation is presented below.

Table 5-5 Primary Energy Production in Thailand

Year	Renewable	Lignite	Crude oil	Condensate	Natural gas
Unit	1000 toe	1000 tonne	bbl/d	bbl/d	MMCFD
1980	10285	1499	274	0	0
1981	10678	1712	313	1287	30
1982	11158	2173	301	5551	129
1983	10912	1997	6578	6660	155
1984	11061	2362	14767	8241	234
1985	11293	5188	21700	14290	362
1986	11149	5476	21200	14265	351
1987	11058	6901	17912	15190	490
1988	10890	7258	20377	17942	580
88/83	0.0%	29.4%	25.4%	21.9%	30.2%

Source: Thailand Energy Situation

(1) Supply of petroleum products

In 1987, supply of petroleum products in Thailand totaled approximately 11,700 ktoe (kilo tonnes of oil equivalent), with 74% coming from domestic refineries and the remaining 26% from foreign suppliers. Approximately 900 ktoe of domestically produced crude oil and approximately 7,200 ktoe of imported crude oil were used. The primary source of domestic crude oil in Thailand are the Sirikit oil fields in Kamphaeng Phet (7.34 million barrels in 1986), but the Fang oil field in

Chiang Mai is also producing a small amount of crude oil (390,000 barrels in 1986). Full-scale exploration for petroleum resources in Thailand began in 1971. Natural gas fields were discovered in the Gulf of Thailand, but no promising oil field discoveries have been made, and the focus is now placed on land rather than in the gulf. The five-year Sixth National Economic and Social Development Plan includes a goal of increasing crude oil production by 1991 to 30,000 barrels/day, up from 20,000 barrels/day in 1985.

Thailand currently has a total refining capacity of approximately 190,000 barrels/day in four refineries, but this is not enough to meet the demands. The oil refiners operating in Thailand are planning to increase their combined refining capacity as shown in Table 5-6.

Table 5-6 Petroleum Refining Capacity
(10,000 bbl/day)

	1987	1990	1991	1993
Refining capacity	19.3	27.6	33.7	52.0
Increase		+8.3	+6.1	+18.3

("+" means increase in ability.)

In 1987, 70% of petroleum products were used by the transportation and communication sectors. The manufacturing sector used 14%, and the agricultural and electric power/gas sectors each used 7%. Consumption of petroleum products in the commercial sector and in homes accounted for 5% of the total consumption. Diesel is the predominantly used in the transportation sector, but this sector also uses one third of total LPG. In the coming years, the transportation sector is expected to require more diesel and LPG than gasoline. Demands for gasoline, diesel and LPG are shown in Table 5-7.

40% of diesel and 10% of gasoline are imported today, and these two products will continue to be imported.

Table 5-7 Demands for Gasoline, Diesel and LPG
(Unit: ktoe)

	1987	Annual Growth	
		Sixth Plan	Next 5 Years
Gasoline	1,935	2.0%	2.6%
H-Diesel	5,451	5.2%	3.4%
LPG	751	7.8%	6.8%

Source: "Energy Development Plan during the Period of the Sixth National Economic and Social Development Plan" 1986 by NESDB

Note: In Thailand, two grades of diesel are used. H-Diesel, which refers to high-speed diesel is equivalent to diesel and low-speed diesel is equivalent to A fuel oil in Japan.

(2) Lignite

There are 10 lignite mines in Thailand, including Mae Mo and Li in the north and Krabi in the south. Lignite reserves are mostly in the northern region. The total confirmed lignite reserve in Thailand is 900 million tons (800 million tons from Mae Mo) and the estimated total minable reserve is 1.6 billion tons (1.3 billion tons at Mae Mo). Lignite production has been increasing

every year, from 1.5 million tons in 1980 to 7.8 million tons in 1988. Recently, the Thailand government decided to conduct study of reserves to promote development of lignite mines and to lease the promising mines to private operators at auction. Consumption status and supply plan of lignite are shown in Table 5-8. In 1987, 86% of lignite was used for electric power generation. 10% was used by the cement manufacturing industry and the remaining 4% was used in the tobacco industry. The Electric-Power Generated Public Corporation of Thailand has constructed thermal electric-power generating plants near lignite mines at Mae Mo to save on transportation cost, and the entire lignite production at Mae Mo is used for electric-power generation.

The Sixth National Economic and Social Development Plan calls for increasing the amount of lignite used for electric-power generation from 5 million tons (740 MW) in 1985 to 9 million tons (1,500 MW) in 1991 by constructing additional generating plants at Mae Mo. Lignite mined in areas other than Mae Mo is used as industrial fuel, primarily by cement and tobacco factories. Under the Sixth National Economic and Social Development Plan, use of lignite as industrial fuel is targeted to increase from 500,000 tons in 1985 to 1,000,000 tons by 1991.

Table 5-8 Supply of Lignite
(1,000 tons/year)

Purpose	1980	1985	1991	91/85
Power generation	1,321	4,597	8,700	11%
Industrial fuel	84	479	1,040	14%
(Tobacco)	(79)	(92)	(80)	
(Cement)	(4)	(387)	(960)	
Total	1,405	5,076	9,740	11%

Source: Thailand Energy Situation 1987 by NEA

(3) Supply of natural gas

Natural gas exploration in the Gulf of Thailand began in 1971, and the first gas well was discovered in 1972. Commercial production began in 1981 at the Erawan gas field in the Gulf of Thailand. Total natural gas production in Thailand was only 30 million cubic feet per day in 1981, but subsequent development, including inland fields, increased production to 560 million cubic feet per day in 1988. There is approximately 4 trillion cubic feet of confirmed natural gas reserves in Thailand, and the estimated recoverable reserve is estimated at 13 trillion cubic feet. The Sixth National Economic and Social Development Plan as shown in Table 5-9 puts 680 million cubic feet per day as the natural gas production goal for 1991.

Table 5-9 Natural Gas Demand Forecast
(Unit: Million cubic ft./day)

	1985	1991	91/85
Natural gas	368	680	10.8%

Source: NESDB, 1987

Natural gas produced offshore in the Gulf of Thailand is transported via pipelines to Rayong. The natural gas separation plan in Rayong separates approximately 15% of the delivered natural gas as LPG, which is supplied for cooking and for automobile fuel throughout the country. The

natural gas from which LPG is extracted is transported via an overland pipeline from Rayong. Most of this natural gas is delivered to the Electricity Generating Authority of Thailand, with the remainder to industrial customers. At the beginning, cement factories were the only industrial users of natural gas, but Petroleum Authority of Thailand has been promoting industrial use of natural gas and several glass factories have so far become regular users of natural gas. Petrochemical plants that use natural gas as raw material also started to operate from Oct. 1989.

5.3.3 Demand and Supply of Energy in Local Regions

In 1983, 96% of renewable energy and 23% of commercial energy were used in local regions. Renewable energy accounts for 74% of total energy consumption in local regions, and commercial energy accounts only for 26%. The Thailand government's energy administration officials have the following long-term (2001) expectations for energy supply in local regions:

- ① Electric-power consumption at homes in local regions will double.
- ② 98% of the villages will have electricity by 2001.
- ③ LPG consumption in homes of the local regions will increase by sixfold.
- ④ Currently, LPG accounts for only 4% of heat for cooking in homes of the local regions, but it will rise to 15% by 2001.
- ⑤ Low income homes of the local regions currently use fire wood, but they are expected to use charcoal in the future.

(Source: "Energy Development Plan during the Period of the Sixth National Economic and Social Development Plan" 1986 by NESDB)

Electricity and LPG are expected to become the primary energy sources for local regions, but, because electricity is used mostly for lighting, LPG is expected to become the primary heating energy source. As shown in Table 5-10, prices per calory between charcoal and LPG approximately equal. It is necessary that some incentives for previaling LPG to local region are inloaded, because to use LPG is required comparative expensive burning equipments.

Table 5-10 Comparative Cost of Charcoal and LPG (1987)

Energy sources	1,000 kcal/t	Baht/t	Baht/1,000 kcal
Charcoal	3,820	3,000- 4,000	0.78-1.05
LPG	12,000	9,800-11,000	0.82-0.92

Considering the pace of regional economic development and the stagnation of demands for renewable energy, what is required of the Thailand government's energy policy administrators is to achieve efficient supply of commercial energy to local regions.

5.4 Environmental Problems in the Samut Prakarn District

The regional dispersion policy, implemented about 10 years ago has made the Samut Prakarn region into an area where small and medium sized factories exist without any sense of order. There are nearly 2,500 factories in this region today, and the Bang Poo and Bang Plee industrial zones in this region are already full. Expansion planning is now underway for the Bang Plee industrial zone. The disorderly proliferation of industrial operations in the Samut Prakarn district has caused industrial pollution problems such as land subsidence, air pollution and water pollution, and the Thailand government is now working on investigation and improvement planning for this region.

The Thailand government began formulating environmental improvement and protection measures for the Samut Prakarn region about five years ago, but there apparently is a gap between the government's plans and the action, and the results are not as rosy as the government states. Summarized below are the government environmental improvement and protection measures in the Samut Prakarn region and the future expectations.

(1) Only export companies are allowed to build factories in the Samut Prakarn district. However, as the expansion plan for the Bang Plee industrial zone indicates, industrial land development in this district is being allowed to proceed by claiming that it is part of the previously approved plan.

(2) The Thailand government has proclaimed that it will no longer approve large scale investments in this district; this policy appears prudent in view of the lack of plans to expand the Southern Bangkok Power-generation Plant, and considering the other industrial zone development projects (such as the southern coastal industrial zone).

(3) Sufficient amounts of low sulfur content fuel oil and natural gas can be supplied to the Southern Bangkok Power-generation Plant. This 1,300 kW plant uses 1.5 million liters of fuel oil each day, but that is only 20–25% of the plant's total fuel consumption. Natural gas fills the remaining fuel needs for this plant. The supplier of natural gas to this plant states that it will continue to be able to supply the necessary amount of natural gas.

(4) Production values in the Samut Prakarn district will grow at a double-digit rate. While large industrial investments will not be made in this district, expansion of small and medium sized factories should be able to maintain a double-digit annual growth rate. The Metropolitan Electricity Authority is forecasting an approximate 6.0% growth in demands for electric power for this industrial region between 1987 and 1991.

5.5 Actions on Environment Problems

Pollution of the Chao Phraya River, land subsidence in industrial districts, industrial discharge of heavy metals and automobile exhaust gases in the city of Bangkok are some of the environmen-

tal problems that have been highlighted in recent years. ONEB and the Ministry of Industry are separately working on these environmental problems, and ONEB is taking the leadership in establishment of environmental standards and formulation of environmental protection programs. In Japan, government, businesses and the public became strongly concerned about industrial pollution in the early 1970's and remedial measures were found relatively efficient. However, in Thailand, even the industrialists still have a low consciousness level on the pollution issue. In the area of air pollution, the automobile exhaust problem in Bangkok has attracted deep concerns and specific actions are being taken, but only some and almost none of the small and medium sized factories are taking actions to reduce smoke emission. Presented below are some of the opinions on the air pollution problem that have been expressed by government officials and officers of large businesses.

(1) Position of ONEB

Thailand's government officials and officers of energy related public corporations and private corporations say that they are following the lead of ONEB in environmental policies and regulations, making ONEB the key institution for improvement and protection of Thailand's environment. Therefore, ONEB is counted upon, not only to formulate the future environmental policies, but to play the leadership role on environmental protection and monitoring technologies.

(2) The environmental protection cost burden for industry

On the average, small and medium sized Japanese companies are estimated to be spending 2% of their gross sales on environmental protection measures. It would be too much to ask the small and medium size companies in the Samut Prakarn industrial district to make similar expenditures on antipollution measures because of their cost competitiveness.

(3) Alternate energy use for environmental protection

The energy pricing mechanism that gives priority to market efficiency is expected to be implemented in Thailand in the future. Under such a policy, urging the use of alternate energy sources for the sake of environmental protection would result in increased production costs. Large corporations and government agencies may be able to absorb such a cost increase, but it is expected that the small and medium sized companies found in the Samut Prakarn industrial district will not be able to switch to alternate energy sources without some form of incentive from the government.

(4) Consumption of lignite

Consumption of lignite, a domestically available energy source, is expected to rise along with consumption of natural gas. Today, lignite is used as fuel for electric-power generation near the mines so that increased use of lignite will not lead to air pollution in the industrial regions of Thailand. At this time, there is no risk of lignite consumption causing air pollution in and near the Samut Prakarn industrial district.

(5) Implementation of energy saving policy as an environmental protection measure

Environmental protection measures require cost and technology, but the current Thailand government's economic policy officials do not welcome having to increase expenditures for environmental programs because of government budget restraints and desire to avoid increasing the costs of industrial products. Environmental program based on energy saving campaign appears to be relatively more easily acceptable to the government officials because it will not result in higher industrial production cost.

6 Energy Saving Countermeasures and Effects

6.1 Simulation for Energy Consumption

(1) Purpose of the simulation

The purpose of this simulation model is to analyze how the economic and energy policies determined by the Thai government will be affected if the countermeasures for combustion source (energy saving measures) are carried out.

(2) Structure of the simulation model

The simulation model calculates the energy consumption of each industry in arranging industry in vertical axes and energy sources in horizontal axes (matrix). Concerning the industrial growth rate and energy consumption required for the simulation model, we used the data estimated by the Thai government. Usage of the simulation model enables to not only estimate Thailand's future energy consumption but also to calculate the influence on energy consumption when energy saving countermeasures are carried out in Thailand. The energy demand of each industry can be calculated as follows:

D_{ijt} : Energy demand of each industry (i: industry, j: energy, t: year):

R_i : Growth rate of each industry

E_{ij} : Energy elastic value of each industry

C_{ij} : Energy saving rate of each industry

The industry energy demand for the year t can be obtained from the demand of the year t - 1 according to the expression below:

$$D_{ijt} = D_{ij(t-1)} \times (1 + R_i \times E_{ij}) \times C_{ij} \dots\dots\dots (6-1)$$

While, an industry's energy demand after n years can be obtained according to the expression (6-2) assuming the initial year to be 0.

$$D_{ijn} = D_{ij0} \times (1 + R_i \times E_{ij})^n \times C_{ij} \dots\dots\dots (6-2)$$

(3) Collection data

To collect data required for the simulation model and to study the economic and energy policies of Thailand, we held hearings for the government agencies and private corporations shown in Table 6-1 from July 11-21, 1988. As a result, the reference material and the calculation results shown below are obtained.

Table 6-1 Visited Government Offices and Corporations Related to Energy in Thailand

<p>Date of visit: July 11, 10:00~11:00</p> <p>Destination: National Economic and Social Development Board. Urban Development Coordination Division</p> <p>Purposes: 1) Obtaining information concerning urban planning and development project 2) Acquiring opinions of the agency concerning air pollution 3) Hearing on the promotion situation of local distribution planning</p>	<p>Date of visit: July 15, 9:30~11:00</p> <p>Destination: Electricity Generating Authority of Thailand</p> <p>Purposes: 1) Hearing on the pollution preventive countermeasures 2) About the future air pollution countermeasures for power plants 3) About the future electric power demand</p>
<p>Date of visit: July 12, 10:00~12:00</p> <p>Destination: National Energy Administration</p> <p>Purposes: 1) Hearing on the lignite development promotion 2) Overall environmental problem in Thailand</p>	<p>Date of visit: July 18, 10:00~12:00</p> <p>Destination: Thailand Development Research Institute</p> <p>Purposes: 1) Hearing on the future prospect of GDP in Thailand 2) About energy elastic value to GDP in Thailand 3) About energy consumption in Samut Prakarn</p>
<p>Date of visit: July 13, 10:00~12:00</p> <p>Destination: Technology and Environmental Planning Division in NESDB</p> <p>Purposes: 1) Role of technical environmental planning section in NESDB 2) Hearing on pollution problems under the high-growth economic situation of Thailand 3) Discussion of air pollution control planning in Samut Prakarn</p>	<p>Date of visit: July 18, 14:00~15:15</p> <p>Destination: The Ministry of Commerce</p> <p>Purposes: 1) Hearing on the price system for petroleum products and natural gas 2) About the import of low sulfur fuel oil</p>
<p>Date of visit: July 13, 11:00~12:30</p> <p>Destination: Government Private Corporation Division in NESDB</p> <p>Purposes: 1) Hearing on the role of government-private division 2) About the role of a private corporation concerning energy and the environment 3) About the role of government offices and public corporations concerning energy and the environment</p>	<p>Date of visit: July 19, 10:00~12:00</p> <p>Destination: Petroleum Authority Thailand (PTT)</p> <p>Purposes: 1) Hearing on natural gas supply planning 2) About the future prospect of crude oil and oil refineries 3) About spreading activity for natural gas</p>
<p>Date of visit: July 14, 10:00~12:00</p> <p>Destination: Industrial Estate Authority of Thailand.</p> <p>Purposes: 1) Hearing on the main industrial estates in Thailand 2) About pollution prevention in the Eastern seaboard development program 3) About the utilization plan for natural gas and Lignite</p>	<p>Date of visit: July 20, 10:00~12:00</p> <p>Destination: Energy Policy Committee</p> <p>Purposes: 1) Correspondence of this committee to environmental problems 2) Views of this committee on energy development and utilization 3) Opinions of this committee concerning environmental protective policies</p>
	<p>Date of visit: July 21, 10:00~11:00</p> <p>Destination: Metropolitan Electricity Authority</p> <p>Purposes: 1) Hearing on the growth rate of electric power supply to metropolitan areas 2) About the selling price of electric power 3) About the growth rate of electric power in local areas</p>

- 1) Actual energy demand/supply and future prospect data
 - Thailand Energy Demand (actual and outlook) Table 6-2
 - Thailand Energy Supply (actual and outlook) Table 6-3
 - Thailand Energy Prices (actual and outlook) Table 6-4

The actual and outlook of 1986, 1987, 1988, 1991, 1996 and 2001 shown in these tables are derived from the references issued by NEPO and NEA, "Thailand Energy Situation" by NEA, "Electric Power in Thailand" by NEA, "Total picture status of Energy in Thailand in the future" by NEPO. The values for 1992 and 1999 are estimated in this survey. In other words, because the short-and long-term strategic prospect years are determined at 1992 and 1999, the calculation years are set as 1992 and 1999. Upon the estimation, the growth rates of energy demand from 1991 to 1996 and from 1996 to 2001, indicated in NEPO and NEA, are adopted.
- 2) Actual energy data of each industry
 - Thailand Energy Utilization by Economic Sector: Table 6-5
 - Thailand LPG Consumption by Economic Sector: Table 6-6
 - Thailand Kerosene Consumption by Economic Sector: Table 6-7
 - Thailand Premium Gasoline Consumption by Economic Sector: Table 6-8
 - Thailand Regular Gasoline Consumption by Economic Sector: Table 6-9
 - Thailand High Speed Diesel Consumption by Economic Sector: Table 6-10
 - Thailand Low Speed Diesel Consumption by Economic Sector: Table 6-11
 - Thailand Fuel Oil Consumption by Economic Sector: Table 6-12

The data shown in these tables are quoted from the "Thailand Energy Situation" 1987 and "Oil and Thailand" 1988 issued by NEA.
- 3) Actual gross domestic product of each industry in Thailand and the future prospect
 - Actual gross domestic product of each industry in Thailand and the future prospect: Table 6-13
 - Energy elastic values to gross domestic product of each industry Thailand: Table 6-14
 - Actual gross domestic product of each industry in Samut Prakarn and the future prospect: Table 6-15

The actual and estimation values of these tables except for 1992 and 1999 are derived from the "National Income Accounts" by NESDB, the "Total Picture Status of Energy in Thailand in the future" by NEPO and TDRl references. The values for 1992 and 1999 are estimated in this survey.

The energy elastic values of each industry shown in Table 6-14 are obtained after calculating the actual data for five years from 1983 to 1988 and hearing from the well-informed persons of the Thailand Development and Research Institute. The obtained energy elastic values are used as the future energy consumption elastic values of each industry (from 1990 to 1999). The elastic values have the following characteristics:

 - ① The mechanization of agriculture will increase the energy elastic value of agriculture in the future.

- ② The upgrade of the Thai people's living standard and increase of hotel construction will augment the energy elastic value of the commercial sector and housing sector in the future.

Table 6-2 Thailand Energy Demand (Actual and outlook)

ITEMS	Sources	Demand Sectors	Unit	1986	1987	1988	Estimated value					
							Upper	Lower	1991	1996	2001	1992
Petroleum Demand	PG		1000 KL	1201.0	1282.0	1427.0	1615.0	2171.0	2784.0	1713.4	2520.4	
	Gasoline		1000 KL	2269.0	2597.0	2923.0	3257.0	4177.0	5156.0	3423.2	4739.5	
	Kerosene		1000 KL	143.1	129.0	125.6	146.7	172.6	191.5	151.5	183.7	
	Diesel		1000 KL	5739.3	8428.1	7215.3	8012.0	30722.0	33661.0	8492.7	32516.6	
	Fuel	Power	1000KL	879.0	602.0	823.0	1000.0	1000.0	1000.0	1000.0	1000.0	
		Industry	1000KL	1531.0	1744.0	1977.0	2241.0	2631.0	3083.0	2314.1	2893.6	
		Export	1000KL	16.0	31.0	0.0	0.0	0.0	0.0	0.0	0.0	
		Total	1000KL	2426.0	2377.0	2800.0	3241.0	3691.0	4083.0	3314.1	3693.6	
		Crude Oil	Refinery	1000KL	10100.0	10188.0	8914.0	11058.0	33363.0	33563.0	11503.7	33363.0
	Other Energy Demand	Condensate	Refinery	1000KL	188.0	259.0	177.0	200.0	200.0	200.0	200.0	200.0
		Export	1000KL	630.0	569.0	864.0	1480.0	2303.0	2303.0	1619.0	2303.0	
		Total	1000KL	828.0	828.0	1041.0	1680.0	2503.0	2503.0	1819.4	2503.0	
Natural Gas		Power	MKCFD	258.0	391.0	467.0	548.0	735.0	852.0	581.1	803.1	
		Industry	MKCFD	10.0	9.5	10.0	12.0	15.0	20.0	12.5	17.8	
		PG	MKCFD	83.0	89.0	103.0	120.0	160.0	180.0	127.1	180.0	
		Total	MKCFD	351.0	489.5	580.0	680.0	910.0	1032.0	720.6	981.4	
		Lignite	Power	KTONS	4685.0	5727.0	5896.0	8736.0	18766.0	19273.0	10172.9	19044.2
		Industry	KTONS	741.0	1298.0	1555.0	1844.0	2388.0	3084.0	1941.8	2784.1	
		Total	KTONS	5426.0	7025.0	7451.0	10580.0	21094.0	22357.0	12114.8	21828.3	
	Coal	Power	KTONS	0.0	0.0	0.0	0.0	0.0	5688.0	0.0	3500.0	
	Industry	KTONS	223.0	315.0	385.0	462.0	642.0	785.0	493.4	724.3		
	Total	KTONS	223.0	315.0	385.0	462.0	642.0	800.0	493.4	1024.3		
	Renewable Energy	Consump	KTOE	1149.0	1165.0	1089.0	1090.0	1100.0	1100.0	1100.0	1100.0	
	Export	KTOE	26.0	37.0	15.0	0.0	0.0	0.0	0.0	0.0		
	Total	KTOE	1175.0	1195.0	1090.0	1090.0	1100.0	1100.0	1100.0	1100.0		
	Electricity	GWH	25458.0	29050.0	32874.0	41000.0	60000.0	78000.0	44244.3	70223.1		

Source : Actual tons of 1986, 1987, 1988 quoted from "Thailand Energy Situation", Oil and Thailand 1988" and "Electric Power in Thailand" compiled by HEA. Growth rate of each Energy quoted from "Total picture status of Energy in Thailand in the future" compiled by NEPD.

Table 6-3 Thailand Energy Supply (Actual and outlook)

ITEMS	Sources	Unit	Upper Estimated value							
			1986	1987	1988	1989	1990			
Energy Production	LPG	KBO COE	1094.0	1049.0	1151.0	1615.0	2171.0	2784.0	3713.0	4520.0
	Gasoline	1000KL	2200.0	2407.0	2510.0	2439.0	2940.0	2980.0	2567.0	2319.0
	Kerosene	1000KL	143.0	128.0	128.0	127.0	123.0	122.0	122.0	121.0
	Diesel	1000KL	3675.0	3668.0	3501.0	3381.0	4677.0	4677.0	4028.0	4677.0
	Fuel Oil	1000KL	2198.0	2135.0	2629.0	2550.0	3074.0	3074.0	2647.0	3074.0
	Trade Oil	1000KL	1230.0	1093.0	1182.0	1345.0	1629.0	1629.0	1897.0	1629.0
	Condensate	1000KL	828.0	828.0	1041.0	1680.0	2503.0	2503.0	1819.0	2503.0
	Natural Gas	MCFD	351.0	480.0	580.0	689.0	910.0	1092.0	721.0	381.0
	Lignite	ATOMS	5428.0	7025.0	7451.0	9580.0	21094.0	22397.0	12116.0	21828.0
	Renewable Energy	KIOWE	1149.0	1050.0	10890.0	1000.0	11000.0	11000.0	10000.0	10000.0
	Electricity	GWH	5554.4	4075.3	3779.0	3600.0	4000.0	4513.0	3639.0	4300.0
	Lignite	GWH	5545.0	4068.0	3805.0	3609.0	2207.0	2272.0	2200.0	2242.0
	Coal	GWH	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
	Fuel Oil	GWH	3395.0	2255.0	3166.0	3950.0	3850.0	3850.0	3850.0	3850.0
	N. G.	GWH	1025.0	13624.0	15720.0	21920.0	29400.0	34080.0	23248.0	32125.0
Other	GWH	0.0	0.0	0.0	1121.5	616.9	639.4	1305.4	21.0	
PC	GWH	2417.4	26692.3	32465.0	41000.0	60000.0	79000.0	4244.0	70223.0	
Gasoline	1000KL	107.0	232.8	276.3	0.0	0.0	0.0	0.0	0.0	
Kerosene	1000KL	7.8	223.0	351.5	817.0	1237.0	2176.0	587.8	1739.1	
Diesel	1000KL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
Fuel Oil	1000KL	2107.0	2665.0	3668.0	8010.0	10718.0	13381.0	8491.2	12517.0	
Trade Oil	1000KL	82.3	335.2	285.7	691.0	568.0	1010.0	651.8	786.1	
Condensate	1000KL	8570.0	9149.0	8732.0	9743.0	11734.0	11734.0	10112.1	11734.0	
Coal	1000KL	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	
PC	KIOWE	223.0	315.0	385.0	462.0	642.0	6473.0	493.4	4224.3	

Source : Actual data of 1986, 1987, 1988 quoted from "Thailand Energy Situation", Oil and Thailand 1988" and "Electric Power in Thailand" compiled by NEA. Growth rate of each energy quoted from "Total picture status of Energy in Thailand in the future" compiled by NEPO.

Table 6-4 Thailand Energy Prices (Actual and outlook)

ITEMS	Source	Unit	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Energy Prices	Exchange Rate	Baht/Dollar	26.3	25.8	25.3	25.0	25.0	25.0	25.0	25.0	25.0	25.0
	Gasoline	\$/bbl	15.8	18.0	15.3	21.4	26.2	32.1	22.3	29.6	29.6	29.6
	Kerosene	\$/bbl	12.9	33.4	35.1	42.6	47.1	47.1	43.0	46.6	46.6	46.6
	Diesel	\$/bbl	20.0	16.4	17.0	19.2	22.3	27.3	19.0	25.2	25.2	25.2
	Fuel Oil	\$/bbl	31.8	11.4	11.4	13.3	16.6	16.1	15.3	15.3	15.3	15.3
	Natural Gas	\$/MCF	3340.0	2950.0	3080.0	3350.0	4120.0	5050.0	3510.0	6500.0	6500.0	6500.0
	Trade Oil	\$/bbl	1460.0	9850.0	9850.0	9800.0	11020.0	12200.0	10000.0	13000.0	13000.0	13000.0
	PC (Small)	\$/bbl	5990.0	29850.0	3850.0	9900.0	11600.0	12400.0	10200.0	16500.0	16500.0	16500.0
	Gasoline (Premium)	\$/bbl	8900.0	6900.0	8450.0	8500.0	10400.0	12000.0	8850.0	11300.0	11300.0	11300.0
	Gasoline (Regular)	\$/bbl	8200.0	6200.0	7750.0	7830.0	9370.0	11000.0	8140.0	10430.0	10430.0	10430.0
	Kerosene	\$/bbl	6120.0	6120.0	6120.0	6700.0	8200.0	10100.0	1010.0	9300.0	9300.0	9300.0
	Diesel (High Speed)	\$/bbl	6300.0	5630.0	5850.0	5390.0	7200.0	9600.0	6670.0	8240.0	8240.0	8240.0
	Diesel (Low Speed)	\$/bbl	5950.0	5340.0	5550.0	5060.0	7440.0	9120.0	6340.0	8400.0	8400.0	8400.0
	Fuel	\$/bbl	3340.0	2950.0	3080.0	2860.0	3510.0	4290.0	2990.0	3950.0	3950.0	3950.0
	Natural Gas	\$/MCF	103.0	90.0	90.0	93.0	109.0	121.0	86.0	120.0	120.0	120.0
Lignite	\$/bbl	350.0	280.0	280.0	260.0	260.0	270.0	260.0	270.0	270.0	270.0	
Coal	\$/bbl	1180.0	950.0	950.0	1120.0	1180.0	1250.0	1130.0	1220.0	1220.0	1220.0	
Renewable Energy	\$/bbl	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	4000.0	
Electricity	\$/kWh	1.9	1.8	1.8	1.8	2.0	2.2	2.4	2.0	2.0	2.0	

Source : The figure of 1986, 1987 and 1988 are actual value. Energy price by NESDB are quoted from "Total picture status of Energy in Thailand in the future" compiled by NEPO. Petroleum price and Other energy price are decided with linked of previous energy prices by this project.

Table 6-5 Thailand Energy Utilization by Economic Sectors (1987)

(Unit :1000 tons of oil equivalent)

		Commercial Energy					SubTotal	Renewable Energy	Total
		Coal	Lignit	Petro.	N. Gas	Electri			
C O N S U M P T	Agriculture			830		6	835		835
	Mining			49			49		49
	Manufacturing	196	478	1,598	40	964	3,276	2,316	5,592
	Construction			111			111		111
	Resident. Commerce.			585		1,136	1,721	4,634	6,355
	Transportation			7,863			7,863		7,863
	Others			171		18	187		187
	Consumption Total	196	478	11,207	40	2,121	14,042	6,950	20,992
S U P P L Y	Supply Total	196	478	11,183	40	2,121	14,018	6,950	20,968
	Energy Conversion		-1420	8,068	-4,350	1,184	3,482	-4,081	-599
	Petroleum Refinery			8,170			8,170		8,170
	NG. Processing			448	-663		-215		-215
	Electricity Plants		-1,420	-550	-3,504	1,538	-3,938		-3,938
	Other Conversion				-183	-354	-537	-4,081	-537
	Primary Energy Sup	197	1,898	3,115	4,390	937	10,537	11,031	21,568
Production		1,932		4,390	903	7,225	11,058	18,283	
Import	197		3,238		35	3,471	10	3,481	
Stocks		-34	-94			-128		-128	
Export	-1		-20		-1	-31	-37	-68	

Note : difference between consumption and supply are statistic error.
Source :Thailand Energy Situation 1987(NEA)

Table 6-6 Thailand LPG Consumption by Economic Sectors

Economic Sectors	1983	1984	1985	1986	1987	1988
1. Agriculture, Forestry and Fishing	4,275	4,342	4,585	4,585	4,585	4,585
2. Mining and Quarrying	3,442	279	81	230	321	608
3. Manufacturing	108,597	125,098	142,609	143,098	133,607	142,592
3.1 Food, Beverages and Tobacco	6,986	9,375	10,389	6,510	8,998	7,302
3.2 Textiles, Wearing Apparel, Leather and Leather Products	14,044	12,167	14,642	15,677	15,766	16,534
3.3 Wood and Wood Products, Including Furniture	77	-	-	-	-	-
3.4 Paper and Paper Products Printing and Publishing	116	347	262	174	143	60
3.5 Chemical, Petroleum, Coal, Rubber and Plastic Products	761	847	1,455	2,657	3,185	4,668
3.6 Non-Metallic Mineral Products Excepts Products of Petroleum and Coal	48,547	55,942	56,926	47,947	55,358	53,902
3.7 Basic Metal Industries	2,867	5,147	6,370	5,638	12,281	13,757
3.8 Fabricated Metal Products, Machinery and Equipment	7,904	2,484	3,643	2,945	10,685	14,375
3.9 Others (Unclassified)	27,295	38,589	48,922	61,510	27,191	31,494
4. Electricity, Gas and Water	-	-	-	-	-	-
5. Construction	-	-	-	-	-	9
6. Trades, Restaurants, Hotels and Residential	365,180	368,259	382,083	720,132	858,845	1,091,485
7. Transport and Communication	282,031	365,844	408,111	330,717	283,404	183,166
8. Financing, Insurance, Real Estate and Business Services	-	-	-	-	-	-
9. Others	66,986	97,746	2,425	2,638	1,677	4,657
Total	830,581	961,568	1,139,894	1,201,400	1,282,439	1,427,102

Source : Oil Companies
Compiled by NEA

Table 6-7 Thailand Kerosene Consumption by Economic Sectors

Unit: 10³ Litres

Economic Sectors	1983	1984	1985	1986	1987	1988
1. Agriculture, Forestry and Fishing	1,552	1,974	1,686	1,484	1,671	1,033
2. Mining and Quarrying	959	906	680	530	522	592
3. Manufacturing	33,599	44,592	46,397	47,055	45,494	46,525
3.1 Food, Beverages and Tobacco	720	826	1,920	1,731	1,215	1,232
3.2 Textiles, Wearing Apparel, Leather and Leather Products	2,242	2,457	2,309	2,891	3,085	3,551
3.3 Wood and Wood Products, Including Furniture	222	-	2	27	22	25
3.4 Paper and Paper Products	348	523	553	675	739	832
3.5 Chemical, Petroleum, Coal, Rubber and Plastic Products	3,629	4,094	12,748	12,435	14,237	14,793
3.6 Non-Metallic Mineral Products						
Except Products of Petroleum and Coal	12,857	14,717	19,139	17,361	16,362	14,233
3.7 Basic Metal Industries	2,299	2,365	2,385	3,140	3,470	3,717
3.8 Fabricated Metal Products, Machinery and Equipment	1,598	715	936	846	693	794
3.9 Others (Unclassified)	9,384	13,290	5,905	7,946	5,616	7,289
4. Electricity, Gas and Water	-	-	-	-	-	-
5. Construction	202	1,569	1,043	364	55	62
6. Trades, Restaurants, Hotels and Residential	170,000	152,220	99,861	90,188	77,942	75,522
7. Transport and Communication	7,715	4,524	2,138	1,856	1,390	-
8. Financing, Insurance, Real Estate and Business Services	-	-	18	21	9	-
9. Others	323,547	84,263	1,860	1,545	1,932	1,491
Total	537,974	390,048	551,683	441,053	428,965	425,555

Source: Oil Companies Compiled by NEA

Table 6-8 Thailand Premium Gasoline Consumption by Economic Sectors

Unit: 10³ Litres

Economic Sectors	1983	1984	1985	1986	1987	1988
1. Agriculture, Forestry and Fishing	2,276	2,294	2,791	3,984	2,808	2,810
2. Mining and Quarrying	351	614	413	372	415	188
3. Manufacturing	7,371	8,559	8,308	7,475	6,528	6,667
3.1 Food, Beverages and Tobacco	1,363	1,415	1,736	1,614	1,240	1,182
3.2 Textiles, Wearing Apparel, Leather and Leather Products	98	129	199	194	197	227
3.3 Wood and Wood Products, Including Furniture	21	21	3	7	3	-
3.4 Paper and Paper Products	816	915	797	631	636	609
3.5 Chemical, Petroleum, Coal, Rubber and Plastic Products	417	253	504	493	653	691
3.6 Non-Metallic Mineral Products						
Except Products of Petroleum and Coal	909	1,945	1,803	1,884	2,002	2,056
3.7 Basic Metal Industries	294	294	264	556	264	182
3.8 Fabricated Metal Products, Machinery and Equipment	2,886	2,899	109	134	973	1,275
3.9 Others (Unclassified)	567	689	2,891	1,962	560	445
4. Electricity, Gas and Water	-	-	-	-	-	-
5. Construction	94	168	948	645	382	327
6. Trades, Restaurants, Hotels and Residential	-	-	-	-	-	-
7. Transport and Communication	696,263	766,067	800,945	880,155	1,065,857	1,245,878
8. Financing, Insurance, Real Estate and Business Services	-	-	348	529	339	-
9. Others	33,563	62,671	35,680	39,593	36,560	43,569
Total	739,918	840,323	849,433	912,751	1,112,889	1,299,457

Source: Oil Companies Compiled by NEA

Table 6-9 Thailand Regular Gasoline Consumption by Economic Sectors

Unit: 10³ Litres

Economic Sectors	1983	1984	1985	1986	1987	1988
1. Agriculture, Forestry and Fishing	58,363	60,906	63,135	67,092	62,588	63,118
2. Mining and Quarrying	1,449	1,810	1,082	597	497	267
3. Manufacturing	4,960	3,675	4,445	3,318	3,670	4,307
3.1 Food, Beverages and Tobacco	1,861	1,411	1,425	1,125	1,102	1,304
3.2 Textiles, Wearing Apparel, Leather and Leather Products	252	158	254	252	214	332
3.3 Wood and Wood Products, Including Furniture	96	66	91	302	263	428
3.4 Paper and Paper Products	-	50	51	190	161	244
3.5 Chemical, Petroleum, Coal, Rubber and Plastic Products	575	288	1,342	570	919	1,147
3.6 Non-Metallic Mineral Products	-	-	-	-	-	-
Excepts Products of Petroleum and Coal	747	726	670	640	588	534
3.7 Basic Metal Industries	36	84	102	102	122	131
3.8 Fabricated Metal Products, Machinery and Equipment	234	-	14	8	110	163
3.9 Others (Unclassified)	539	892	494	128	169	4
4. Electricity, Gas and Water	-	-	-	-	-	-
5. Construction	710	685	1,423	1,211	999	1,075
6. Trades, Restaurants, Hotels and Residential	-	-	-	-	-	-
7. Transport and Communication	1,189,358	1,142,354	1,112,222	1,210,258	1,364,814	1,513,130
8. Financing, Insurance, Real Estate and Business Services	-	-	36	133	3	-
9. Others	71,990	68,302	58,060	53,578	51,124	41,152
Total	1,327,010	1,277,731	1,340,403	1,336,187	1,463,795	1,621,069

Source: Oil Companies
Compiled by NEA

Table 6-10 Thailand High-speed Diesel Consumption by Economic Sectors

Unit: 10³ Litres

Economic Sectors	1983	1984	1985	1986	1987	1988
1. Agriculture, Forestry and Fishing	1,141,947	1,116,391	896,297	942,617	899,377	896,789
2. Mining and Quarrying	80,783	76,834	65,576	34,072	40,631	41,182
3. Manufacturing	175,883	158,065	183,126	179,307	174,353	150,443
3.1 Food, Beverages and Tobacco	83,390	69,910	107,000	110,665	103,492	77,377
3.2 Textiles, Wearing Apparel, Leather and Leather Products	4,975	4,247	4,734	4,674	3,692	3,499
3.3 Wood and Wood Products, Including Furniture	743	2,921	5,187	3,858	3,743	1,682
3.4 Paper and Paper Products	2,848	3,303	3,602	4,109	5,462	6,056
3.5 Chemical, Petroleum, Coal, Rubber and Plastic Products	11,045	3,340	10,539	10,235	9,159	7,611
3.6 Non-Metallic Mineral Products	-	-	-	-	-	-
Excepts Products of Petroleum and Coal	22,317	25,997	27,974	23,115	22,482	22,903
3.7 Basic Metal Industries	2,648	2,373	4,539	4,959	4,658	5,261
3.8 Fabricated Metal Products, Machinery and Equipment	8,390	877	1,082	1,091	3,618	4,791
3.9 Others (Unclassified)	38,932	45,095	17,369	16,500	18,047	21,063
4. Electricity, Gas and Water	40,839	26,312	18,636	14,784	10,926	7,619
5. Construction	81,073	101,953	123,555	117,193	110,182	91,535
6. Trades, Restaurants, Hotels and Residential	1,601	1,399	1,329	1,026	1,216	-
7. Transport and Communication	1,660,366	1,706,706	1,949,430	1,992,147	1,475,660	1,48
8. Financing, Insurance, Real Estate and Business Services	-	-	34	146	-	-
9. Others	136,133	154,368	129,566	149,575	106,278	270,899
Total	4,318,674	4,577,025	4,472,068	4,669,049	4,335,110	4,118,415

Source: Oil Companies
Compiled by NEA

Table 6-11 Thailand Low-speed Diesel Consumption by Economic Sectors

Unit: 10³ Litres

Economic Sectors	1983	1984	1985	1986	1987	1988
1. Agriculture, Forestry and Fishing	2,628	9,397	7,564	2,100	924	523
2. Mining and Quarrying	3,771	2,766	2,634	1,783	378	278
3. Manufacturing	28,039	30,866	31,332	14,943	14,902	17,310
3.1 Food, Beverages and Tobacco	1,781	1,897	2,196	1,319	1,169	1,155
3.2 Textiles, Wearing Apparel, Leather and Leather Products	326	154	208	227	222	357
3.3 Wood and Wood Products, Including Furniture	-	48	4	2	-	-
3.4 Paper and Paper Products	-	49	-	630	372	-
3.5 Chemical, Petroleum, Coal, Rubber and Plastic Products	1,437	1,967	2,153	1,442	760	1,495
3.6 Non-Metallic Mineral Products Except Products of Petroleum and Coal	1,417	2,479	3,672	2,909	2,369	1,907
3.7 Basic Metal Industries	351	1,837	1,923	3,045	5,610	3,023
3.8 Fabricated Metal Products, Machinery and Equipment	1,098	1,391	1,770	1,411	1,463	1,633
3.9 Others (Unclassified)	19,079	20,744	19,421	3,938	2,992	1,336
4. Electricity, Gas and Water	-	-	-	-	-	-
5. Construction	84	42	24	309	1,352	-
6. Trades, Restaurants, Hotels and Residential	-	-	-	2,671	53	147
7. Transport and Communication	48,228	57,453	36,937	48,437	74,395	82,423
8. Financing, Insurance, Real Estate and Business Services	-	-	-	-	-	-
9. Others	853	1,805	1,345	99	989	2,139
Total	81,603	102,339	79,876	70,342	92,993	96,375

Source: Oil Companies
Compiled by NEA

Table 6-12 Thailand Fuel Oil Consumption by Economic Sectors

Unit: 10³ Litres

Economic Sectors	1983	1984	1985	1986	1987	1988
1. Agriculture, Forestry and Fishing	2,108	2,118	3,447	4,818	916	878
2. Mining and Quarrying	26,798	15,727	14,083	19,942	13,546	12,317
3. Manufacturing	1,214,920	1,198,968	1,167,669	1,216,773	1,393,466	1,604,591
3.1 Food, Beverages and Tobacco	189,638	237,625	268,040	256,253	254,919	289,111
3.2 Textiles, Wearing Apparel, Leather and Leather Products	221,056	234,545	229,388	267,939	301,811	361,201
3.3 Wood and Wood Products, Including Furniture	2,523	2,416	13,925	15,313	18,907	31,682
3.4 Paper and Paper Products	100,538	82,349	113,481	115,883	104,469	100,684
3.5 Chemical, Petroleum, Coal, Rubber and Plastic Products	66,193	55,830	52,410	42,516	66,013	106,027
3.6 Non-Metallic Mineral Products Except Products of Petroleum and Coal	433,319	345,683	340,282	337,874	425,694	428,260
3.7 Basic Metal Industries	32,837	86,779	86,083	91,296	88,943	89,713
3.8 Fabricated Metal Products, Machinery and Equipment	8,407	12,166	7,471	6,649	7,115	8,744
3.9 Others (Unclassified)	103,379	141,373	56,587	83,050	123,593	189,169
4. Electricity, Gas and Water	1,832,112	1,611,911	893,002	865,848	574,972	830,745
5. Construction	9,406	10,813	13,910	21,196	14,642	19,139
6. Trades, Restaurants, Hotels and Residential	4,848	4,528	4,673	11,944	18,487	13,801
7. Transport and Communication	239,575	242,075	174,688	259,558	319,217	311,645
8. Financing, Insurance, Real Estate and Business Services	-	-	-	-	-	-
9. Others	34,574	38,955	9,358	10,114	10,687	6,949
Total	3,164,291	3,125,095	2,280,832	2,410,193	2,345,932	3,000,065

Source: Oil Companies
Compiled by NEA

Table 6-13 Thailand Gross Domestic Product by Economic Sectors (actual and outlook)

SECTORS	1987	1988	1991	1996	1997	1992	1999
Agriculture & Fishery	71535	71535	1.6	1.8	1.8	3.3	3.4916
Mining and Quarrying	10270	10270	2.1	3.0	3.3	3.3	1.4126
Manufacturing: Whole	21374	21374	6.3	5.7	7.4	8.0	140122
Manuf: Food, beverages, tobacco	24865	24865	6.0	5.0	5.6	5.4	32873
Manuf: Textiles, wear, leather	21584	21584	11.0	7.0	10.2	7.2	35011
Manuf: wood, furniture	2253	2253	10.0	6.8	9.4	6.8	3524
Manuf: Paper, printing, publishing	2743	2743	7.0	6.0	6.0	6.0	3812
Manuf: Chemicals, rubber, oil, coal, plastic	22142	22142	8.0	7.3	7.9	6.7	32323
Manuf: Nonmetallic mineral	6466	6466	13.0	5.5	11.5	5.7	11123
Manuf: Basic metal	1019	1019	9.0	1.0	6.8	5.9	1628
Manuf: Fabricated metal, machinery, equipment	12639	12639	8.5	1.5	6.5	8.3	18929
Manuf: Others	4213	4213	10.0	5.3	5.7	6.0	5870
Electricity & Gas & Water	12529	12529	7.8	5.3	7.3	5.6	11816
Construction	17342	17342	7.4	7.7	7.3	7.3	24950
Trade, Restaurants, Hotels & Residential	94427	94427	4.8	5.0	4.8	4.8	119600
Transportation	32703	32703	5.5	5.0	5.5	5.4	4539
Finance, insurance & communication	13250	13250	6.0	5.6	4.8	5.9	17665
Real estate, service	85763	85763	5.0	5.0	5.0	5.0	109458
GDP Total	441893	441893	5.6	4.8	5.9	5.3	569121

UNIT : Value are 1972 constant price
 : Value units are Million Baht
 : Growth rate are %
 SOURCE : 1987 and 1988 values are quoted from NESDB, "National Income Accounts"
 : Total Picture Status of Energy in Thailand in the Future
 : Sector Values in Manufacturing are estimated by this project.
 : Sector growth rate in Manufacturing are quoted from TDRI study.

Table 6-14 Thailand Energy Elastic Value to GDP by Economic Sectors

INDUSTRY	UNIT	1983	1984	1985	1986	1987	1988	Adopted Elastic Value
Agriculture & Fishery	Energy Consump.	KTOE	1043	1023	841	885	854	
	Product Value	Bt/B	183	183	183	183	183	4.4
	Elastic Values		0.2	0.2	0.2	0.2	0.2	-0.1
	Consumer prices	197.9	189.5	194.1	197.7	202.6	218.0	2.5
Mining & Quarry	Energy Consump.	KTOE	102	96	74	53	49	
	Product Value	Bt/B	20	20	20	20	20	13.6
	Elastic Values		0.2	0.2	0.2	0.2	0.2	0.0
	Consumer prices	187.9	189.5	194.1	197.7	202.6	218.0	3.0
Manufacturing	Energy Consump.	KTOE	4547	4900	5019	5250	5598	
	Product Value	Bt/B	194	218	247	267	293	319
	Elastic Values		0.9	0.9	0.9	0.9	0.9	0.7
	Consumer prices	187.9	189.5	194.1	197.7	202.6	218.0	1.7
Construction	Energy Consump.	KTOE	78	100	125	123	111	
	Product Value	Bt/B	30	30	30	30	30	4.7
	Elastic Values		0.2	0.2	0.2	0.2	0.2	0.5
	Consumer prices	187.9	189.5	194.1	197.7	202.6	218.0	1.1
Transportation	Energy Consump.	KTOE	5093	5363	5600	5828	6014	
	Product Value	Bt/B	61	61	61	61	61	14.1
	Elastic Values		0.9	0.9	0.9	0.9	0.9	0.3
	Consumer prices	187.9	189.5	194.1	197.7	202.6	218.0	3.0
Commercial & Service & Resident & Others	Energy Consump.	KTOE	6174	6237	6423	6380	6370	
	Product Value	Bt/B	378	403	421	456	506	537
	Elastic Values		0.9	0.9	0.9	0.9	0.9	0.3
	Consumer prices	187.9	189.5	194.1	197.7	202.6	218.0	1.2
GDP (Above Total)	Energy Consump.	KTOE	17021	18272	18858	19538	21048	
	Product Value	Bt/B	910	973	1014	1100	1224	1468
	Elastic Values		0.9	0.9	0.9	0.9	0.9	0.3
	Consumer prices	187.9	189.5	194.1	197.7	202.6	218.0	1.0

UNIT : KTOE = 1000 ton of energy oil equivalent
 : Energy Consump. = KTOE, the value is nominal
 : Product Value = Bt/B, the value is nominal
 : Consumer Price 1972=100
 SOURCES : Thailand Energy Situation 1988 published by IEA
 : Oil and Thailand 1988 published by IEA
 : Electric Power in Thailand 1988 published by IEA
 : "National Income Accounts" published by NESDB
 : "Country Profile Thailand" published by Economic Intelligence Unit Co. Ltd
 : 1988's product values by sector are estimated with Total GDP, Energy consumption and 1987's production value.

Table 6-15 Samut Prakarn's Gross Domestic Product

		Samut Prakarn			Whole Thailand			Rate		
		1983	1984	1985	1983	1984	1985	1983	1984	1985
Agriculture										
Fishing	Mill. Baht	853.7	723.5	752.5	70081.0	73977.0	78539.0	0.9	1.0	1.0
Forestry										
Mining										
Quarrying	Mill. Baht	115.8	149.3	217.8	7988.0	9535.0	9901.0	1.4	1.8	2.2
Manufacturing										
	Mill. Baht	9458.9	9847.3	9789.0	76773.0	81962.0	81463.0	12.3	11.8	12.0
Electricity										
Gas	Mill. Baht	747.6	819.8	883.7	8253.0	9023.0	9933.0	9.1	9.1	8.9
Water										
Construction										
	Mill. Baht	197.4	198.3	209.4	15787.0	17547.0	16635.0	1.3	1.1	1.3
Trade										
Restaurants	Mill. Baht	1009.7	1051.8	1089.6	73676.0	78723.0	81519.0	1.4	1.3	1.3
Residential										
Transportation										
Communication	Mill. Baht	280.4	328.1	350.3	24536.0	27074.0	29171.0	1.1	1.2	1.2
Financing										
Insurance	Mill. Baht	334.1	367.2	401.2	10524.0	11533.0	11772.0	3.2	3.2	3.4
Services										
Others	Mill. Baht	553.5	573.0	605.1	67810.0	71363.0	76179.0	0.8	0.8	0.8
Total	Mill. Baht	13371.1	13858.3	14298.6	355408.0	380738.0	394113.0	3.8	3.5	3.6

Sources : NESDB
Value are 1972 constant prices

6.2 The Energy Demand Prospect before Energy Saving in Thailand

The energy demand prospect before the energy saving countermeasure implemented (the base case) is estimated by the Thai government until 2001 (according to "Total picture status of Energy in Thailand in the Future" by NEPO January 1988). Thus the energy demand summation of individual industries calculated from the simulation model (See Tables 6-16 through 6-24) approximately coincides with the energy demand estimated by the Thai government. Concretely speaking, the elastic values shown in Table 6-14 are given as the initial value, after that the energy elastic values of each industry are corrected so as to approach to the estimation value of the Thai government. Tables 6-25 and 6-26 compile the differences.

Table 6-17 Thailand Diesel Consumption (base case)

Industry	Items	U n i t	1987	1990	1992	1993	30/87	37/90	39/91	39/92	37/90	39/91	39/92
Agriculture	Production	1000 kL	0.3120	0.3120	0.3120	0.3120							
	Consumption	1000 kL	8700.0	8700.0	8700.0	8700.0							
	S.S. rate	%	5488.0	5372.5	6303.0	8700.0							
Fishing	Production	1000 kL	700	317	109	109							
	Consumption	1000 kL	100	100	100	100							
	S.S. rate	%	700	217	9	9							
Forestry	Production	1000 kL	530	530	530	530							
	Consumption	1000 kL	431	431	431	431							
	S.S. rate	%	81	81	81	81							
Mining	Production	1000 kL	10	10	10	10							
	Consumption	1000 kL	10	10	10	10							
	S.S. rate	%	10	10	10	10							
Quarrying	Production	1000 kL	41	59	71	71							
	Consumption	1000 kL	31	44	51	51							
	S.S. rate	%	10	10	10	10							
Manufacturing	Production	1000 kL	225	303	383	537							
	Consumption	1000 kL	41	59	71	71							
	S.S. rate	%	18	19	18	13							
Food	Production	1000 kL	101	111	120	161							
	Consumption	1000 kL	50	103	112	144							
	S.S. rate	%	49	92	93	89							
Beverages	Production	1000 kL	41	108	114	144							
	Consumption	1000 kL	37	115	121	137							
	S.S. rate	%	90										

Table 6-18 Thailand Fuel Oil Consumption (base case)

Industry	Items	1987		1990		1993		1997		1999		2007		2017		2027		2037		2047				
		Volume 1000 kL	Weight 1000 Gcal	Volume 1000 kL	Weight 1000 Gcal	Volume 1000 kL	Weight 1000 Gcal	Volume 1000 kL	Weight 1000 Gcal	Volume 1000 kL	Weight 1000 Gcal	Volume 1000 kL	Weight 1000 Gcal	Volume 1000 kL	Weight 1000 Gcal	Volume 1000 kL	Weight 1000 Gcal	Volume 1000 kL	Weight 1000 Gcal	Volume 1000 kL	Weight 1000 Gcal	Volume 1000 kL	Weight 1000 Gcal	
Agriculture	Physical	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	
	Chemicals	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	
	Textiles	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412
	Food	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412
	Other	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412
Manufacturing	Physical	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412
	Chemicals	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412
	Textiles	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412
	Food	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412
	Other	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412
Services	Physical	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412
	Chemicals	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412
	Textiles	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412
	Food	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412
	Other	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412	0.9412

Comment: Growth rate = Industrial product's growth rate
 Elastic value = Rate between energy consumption growth rate and industrial growth rate
 C.S. rate = Energy Conversion rate or Energy saving rate
 KTOE = 1000 Ton of Oil Equivalent
 Gcal = 1,000,000 kcal

Table 6-21 Thailand Lignite Consumption (base case)

Industry	1987	1990	1993	1997	2001	2020	2032	2042
Agriculture Fishing Forestry	Consumption	0.3700	0.3700	0.3700	0.3700	0.3700	0.3700	0.3700
	1000 kcal/yr	3500.0	3500.0	3500.0	3500.0	3500.0	3500.0	3500.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Mining Quarrying	Consumption	1.5	7.5	3.3	3.3	3.3	3.3	3.3
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	Consumption	5.6	5.6	5.6	5.6	5.6	5.6	5.6
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Food	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Beverages	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Textiles	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Textiles Textiles	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Food Food Products	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Paper	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Printing	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Textiles Textiles	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Plastics	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Nonmetallic Mineral	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Basic Metal	Consumption	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	1000 kcal/yr	100.0	100.0	100.0	100.0	100.0	100.0	100.0
	Volume	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Weight	1.0	1.0	1.0	1.0	1.0	1.0	1.0
	Value	100.0	100.0	100.0	100.0	100.0	100.0	100.0

Comment :
 Growth rate = Industrial product's growth rate
 Elastic value = Rate between energy consumption, growth rate and industrial growth rate
 C.S. = Energy conversion rate or Energy saving rate
 YTOR = 1000 Tons of Oil Equivalent
 Gcal = 1,000,000 kcal

Table 6-22 Thailand LPG Consumption (base case)

Industry	1981	1982	1983	1987	1990	1992	1999	20/01	22/90	25/92	27/97
Agriculture	Physical	0.4301	0.4301	0.4301	0.4301	0.4301	0.4301	0.4301	0.4301	0.4301	0.4301
	Consistent	5160.0	5160.0	5160.0	5160.0	5160.0	5160.0	5160.0	5160.0	5160.0	5160.0
Fishing	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Forestry	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Mining	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Quarrying	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Food	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Beverages	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Textiles	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Wearing	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Food Products	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Paper	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Printing	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Chemical	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Petroleum	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Plastics	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Nonmetallic	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Mineral	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Basic Metal	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0
Manufacturing	Physical	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
	Consistent	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0	100.0