5.2.1 Thermoelectric Power Plant (A)

(1) Power Generation Boiler (No.1)

1) Specification of facility

Model	Water-tube boiler (tangential firing)
Capacity	476 ton/hr
Draft and ventilation	Forced draft
Size of furnace	$7{,}900^{W} \times 7{,}900^{D} \times 18{,}500^{H}$
Number and layout of burner	5 stages x 4 = 20
Furnace pressure	+150 mmAq
Ancillary facility	Air preheater (110 → 240°C)

2) Specification of burner

Model	Gas-oil combination: Gas: Lance type Oil: Internal mixing type
Type of fuel	Natural gas and heavy oil
Fuel consumption	1,620 Nm^3/hr/burner (natural gas) 1,620 l/hr/burner (heavy oil)
Fuel pressure	Natural gas : 1 kg/cm^2g, Heavy oil : 8 kg/cm^2g
Atomizing pressure	10 kg/cm^2g (steam)
(Fuel ratio in calory during survey :	Natural gas : 95%, Heavy oil: 5%)

3) Analytical data of flue gas

(Stack sampling data) 15:30/Load is approx. 91% of rating

NOx (ppm)*	156	Particulate matter (g/Nm^3)	0.045
O_2 (%)	3.6	Flue gas temperature (°C)	159
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	1.3
CO_2 (%)	8.3		

(Emission)

	kg/hr
NOx	140
SO_2**	110
Particulate	19

NOx at rated operation is estimated to be 156 ppm (154 kg/hr).

* Converted to the condition of oxygen concentration at 5%.

** Calculated from sulfur content of fuel

4) Observation

This is a tangential firing CE boiler. At the four corners of the horizontal section of the boiler, burners are installed to spray fuel in the off-center orientation. The flames form a fire ball swirling in the horizontal plane. Four burners in one plane form a set, and in the boiler, 5 sets of burners, 20 in total, are installed vertically. All the burners are gas/heavy-oil mixed combustion type.

At the time of the survey, 18 burners were burning natural gas, and only one was burning heavy oil. The natural gas to heavy oil ratio was 95:5.

The NOx concentration of 156 ppm as given by the analysis is average for natural gas combustion, but in view of the large size of this boiler, it may be considered a little too high. This NOx concentration is higher than those of the No. 2 and No. 3 boilers, which employ similar tangential firing type. The essential difference between these boilers is that the No. 1 boiler does not have a flue gas circulation fan to regulate temperature of the combustion chamber.

The low PM concentration of 45 mg/Nm^3 is normal for this boiler with 95% gas. The flue gas O_2 concentration of 1.3% indicates a proper air ratio for a large boiler.

5) Countermeasures

i) Retrofitting of combustion equipment

(a) Complete automatic operation with the installation of combustion control and safety control instruments

(b) Low air ratio combustion through continuous monitoring of the flue gas O_2 concentration

(c) Quasi 2-stage combustion (burner-cut method) or in-furnace denitration combustion

(d) Exhaust gas recirculation by installing the flue gas blower

ii) Fuel change

(a) Mixed combustion with 50% natural gas and 50% heavy oil up to the supply start of desulfurized heavy oil

(b) Mixed combustion with 50% natural gas and 50% desulfurized heavy oil when supply of desulfurized heavy oil is started. The use of desulfurized heavy oil emulsion should be taken into consideration after thorough demonstration tests.

iii) Regular monitoring of the flue gas by installing the NOx and SO_2 telemeters

iv) When the heavy oil mixing ratio is increased over the current level, the installation of an electrostatic precipitator equipped with an ammonia injection system is desired.

6) Expenses for retrofitting of the combustion unit (boiler)

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	69,200
(b)	Flue gas recirculation fan	1 set	84,600
(c)	Combustion control system and instrumentation	1 set	307,700
(d)	Safety control system	1 set	230,800
(e)	On-site work supervision	1 set	69,200
(f)	On-site instruction for test operation	1 set	15,400
(g)	Package and freight	1 set	64,600
(h)	Travelling	1 set	43,000
(i)	Unexpected expenses (5% of the above)		44,220
	Sub-total		928,720

ii) Local portion

			(US$)
(j)	Burner and duct removal	1 set	153,800
(k)	Duct fabrication	1 set	369,000
(l)	Burner, duct, fan installation	1 set	153,800
(m)	Test operation and adjustment	1 set	9,200
(n)	Customs and other taxes	1 set	175,000
(o)	Warehouse, customs clearance, and land freight (incl. IVA)	1 set	18,000
(p)	Freight of duct, etc. and crane rental	1 set	13,000
(q)	IVA (15% excl. n + o)		104,820
	Sub-total		996,620
	Total		US$ 1,925,340

(2) Power Generation Boiler (No.2 and No.3)

1) Specification of facility

Model	Water-tube boiler (tangential firing)
Capacity	504 ton/hr
Draft and ventilation	Forced draft
Size of furnace	$9{,}000^{W} \times 9{,}000^{D} \times 2{,}400^{H}$
Number and layout of burner	6 stages x 4 = 24
Furnace pressure	+450 mmAq (No. 2 boiler), +300 mmAq (No. 3 boiler)
Ancillary facility	Air preheater (110 → 350°C) Flue gas recirculation fan for in-furnace temperature regulation : 7,650 Nm^3/min

2) Specification of burner

Model	Gas-oil *mixed combustion system* Gas : lance type, Heavy oil : mechanical atomizing return flow type
Type of fuel	Natural gas and heavy oil
Fuel consumption	Natural gas : 2,200 Nm^3/hr/burner, Heavy oil : 2,160 l/hr/burner
Fuel pressure	Natural gas : 1 kg/cm^2g, Heavy. oil: 50 kg/cm^2g

Fuel ratio at the time of survey in calorific value ratio:

i) No. 2 boiler, condition 1	Natural gas 97%, Heavy oil 3% (4 Sept. 1990 13:00)
ii) No. 2 boiler, condition 2	Natural gas 45%, Heavy oil 55% (13 Sept. 1990 14:00)
iii) No. 3 boiler, condition 1	*Natural gas 60%,* Heavy oil 40% (14 Nov. 1990 15:00)

3) Analytical data of flue gas

i) No. 2 boiler, condition 1: Natural gas 97%, Heavy oil 3%

(Stack sampling data) 13:00/Load is approx. 92% of rating

NOx (ppm)*	83	Particulate matter (g/Nm^3)	0.0047
O_2 (%)	4.5	Flue gas temperature (°C)	177
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	3.8
CO_2 (%)	8.4		

(Emission)

	kg/hr
NOx	75
SO_2**	60
Particulate	2.0

NOx at rated operation is estimated to be 83 ppm (82 kg/hr).

* Converted to oxygen concentration of 5%.

** Calculated from analytical value of fuel

ii) No. 2 boiler, condition 2: Natural gas 45%, Heavy oil 55%

(Stack sampling data) 14:00/Load is approx. 100% of rating

NOx (ppm)*	103	Particulate matter (g/Nm^3)	0.47
O_2 (%)	5.3	Flue gas temperature (°C)	152
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	4.6 estim.
CO_2 (%)	9.8		

(Emission)

	kg/hr
NOx	100
SO_2**	1,400
Particulate	240

* Converted to oxygen concentration of 5%.

** Calculated from analytical value of fuel

iii) No. 3 boiler, condition 1: Natural gas 60%, Heavy oil 40%

(Stack sampling data) 15:00/Load is approx. 93% of rating

NOx (ppm)*	143	Particulate matter (g/Nm^3)	–
O_2 (%)	8.4	Flue gas temperature (°C)	132
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	6.3
CO_2 (%)	7.3		

(Emission)

	kg/h
NOx	150
SO_2**	1,100
Particulate	–

NOx at rated operation is estimated to be 143 ppm (161 kg/hr).

* Converted to oxygen concentration of 5%.

** Calculated from analytical value of fuel

4) Observation

The No. 2 and No. 3 boilers are both the tangential firing types of the same model and same size. Six sets of burners, 24 in total, each set consisting of 4 corner burners, are installed in each boiler: the bottom 2 sets burn only natural gas, the 3rd and 4th burn gas and oil, and the top two (5th and 6th) burn only heavy oil.

At the time of the diagnostic survey, the top two sets of oil burners were out of operation, and only the 1st to 4th sets from the bottom were in operation. The top two sets of heavy oil burners were said to have their air registers fully closed, but there were some leaks. This mode of operation is called quasi 2-stage combustion or burner cut method.

In the No.2 and No. 3 boilers, a flue gas recirculation fan is installed for regulation of the boiler interior temperature. On the day of the survey, the fan was in operation and flue gas was in circulation, although the flow rate was unknown. The flue gas is introduced into the boiler not through the burner resister together with combustion air, but directly from the bottom of the boiler into the combustion chamber. Since this recirculation system is not intended for NOx reduction, the NOx reduction effect is not known. However, while only the bottom burner sets are in operation, substantial NOx reducing effects are expected.

The measured PM concentration for the No. 2 boiler under condition 1, burning 97% gas, is satisfactory at large. The low NOx concentration at 83 ppm is considered to be due to the 2-stage combustion and the flue gas recirculation, as explained above.

To determine the level of increase in the NOx concentration due to the increase of heavy oil, the flue gas was analyzed after increasing the oil ratio to the same level of that of natural gas, as in the condition 2 for the No. 2 boiler and the condition 1 for the No. 3 boiler. The PM concentration was sharply increaseed with the increase of the heavy oil ratio. The NOx concentration also increased; this was ascribed to the increased generation of fuel NOx resulting from the increased heavy oil. The change was not simple, however, and the NOx concentration varied also with the O_2 concentration in the flue gas. The reason for the lower NOx concentration with 55% heavy oil than with 40% heavy oil is that the air ratio was lower at 1.28 (O_2 : 4.6%) for 55% heavy oil than that at 1.43 (O_2 : 6.3%) for 40%

heavy oil. Because the NOx - air ratio relation is that the NOx concentration increases with increase in the air ratio, the increase in NOx by the increased air ratio for 40% heavy oil superceded the decrease in fuel NOx brought about by the decreased amount of heavy oil.

The flue gas O_2 levels of 3.8% to 6.3% indicate improper air ratios for a large boiler. Reduction to below 2% to a proper air ratio is recommended. Note that for oil combustion, the air ratio should be higher than that for gas combustion.

5) Countermeasures

i) Retrofitting of combustion equipment

(a) Complete automatic operation with the installation of combustion control and safety control instruments

(b) Low air ratio combustion through continuous monitoring of the flue gas O_2 concentration

(c) Exhaust gas recirculation by installing flue gas blower

(d) Quasi 2-stage combustion (burner cut method) or in-furnace denitration combustion

ii) Fuel change

(a) Mixed combustion with 80% natural gas and 20% heavy oil up to the supply start of desulfurized heavy oil

(b) Mixed combustion with 50% natural gas and 50% desulfurized heavy oil when supply of desulfurized heavy oil is started. The use of desulfurized heavy oil emulsion should be taken into consideration after thorough demonstration tests.

iii) Regular monitoring of the flue gas by installing the NOx and SO_2 telemeters

iv) When the heavy oil mixing ratio is increased over the current level, the installation of an electrostatic precipitator equipped with an ammonia injection system is desired.

6) Expenses for retrofitting of the boilers (No.2 and No.3)

The existing flue gas recirculation blower will be used, and the cost will be excluded from the estimation.

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	69,200
(b)	Combustion control system and instrumentation	1 set	307,700
(c)	Safety control system	1 set	230,800
(d)	On-site work supervision	1 set	69,200
(e)	On-site instruction for test operation	1 set	15,400
(f)	Package and freight	1 set	37,700
(g)	Travelling	1 set	43,000
(h)	Unexpected expenses (5% of the above)		38,650
	Sub-total		811,650

ii) Local portion

			(US$)
(i)	Burner and duct removal	1 set	153,800
(j)	Duct fabrication	1 set	369,000
(k)	Burner, duct, fan installation	1 set	123,800
(l)	Test operation and adjustment	1 set	9,200
(m)	Customs and other taxes	1 set	147,000
(n)	Warehouse, customs clearance, and land freight (incl. IVA)	1 set	11,900
(o)	Freight of duct, etc. and crane rental	1 set	11,500
(p)	IVA (15% excl. m + n)		100,100
	Sub-total		926,300

Total 2 x 1,737,950 = US$ 3,475,900

(3) Power Generation Boiler (No.4)

1) Specification of facility

Model	Water-tube boiler (opposed firing)
Capacity	900 ton/hr
Draft and ventilation	Forced draft
Size of furnace	$9{,}745^{W} \times 9{,}745^{D} \times 32{,}918^{H}$
Number and layout of burner	Front : 3 stage x 3 = 9
	Rear : 2 stage x 3 = 6
	Total : 15 burners
Furnace pressure	+300 mmAq
Ancillary facility	Recuperator (75 → 280°C) x 2
	Flue gas recirculation fan for furnace interior temperature regulation : 1,588 Nm^3/min x 2

2) Specification of burner

Model	Gas-oil mixed combination: Gas: lance, Oil: Y-jet mixing
Type of fuel	Natural gas and heavy oil
Fuel consumption	Natural gas : 5,600 Nm^3/hr/burner
	Heavy oil : 3,125 l/hr/burner
Fuel pressure	Natural gas : 1 kg/cm^2g,
	Heavy oil : 10 kg/cm^2g
Atomizing pressure:	18 kg/cm^2g (steam)

(Fuel ratio during survey was 89% gas to 11% oil on the calory base.)

3) Analytical data of flue gas

(Stack sampling data) 15:00/Load is approx. 92% of rating

NOx (ppm)*	170	Particulate matter (g/Nm^3)	0.12
O_2 (%)	7.0	Flue gas temperature (°C)	182
CO (%)	0.10	Combustion chamber outlet O_2 (%)	1.6
CO_2 (%)	6.6		

(Emission)

	kg/hr
NOx	260
SO_2**	420
Particulate	100

NOx at rated operation is estimated to be 170 ppm (260 kg/hr).

* Converted to oxygen concentration of 5%.

** Calculated from analytical value of fuel

4) Observation

This boiler is the largest in this station, and is different in type from the other three. It is a B&W boiler, with two opposed burner sets, front and rear, in contrast to the tangential type used in the No. 1 to No. 3 boilers.

Ljungstrom rotary regenerative air preheaters are usually used for large boilers. Tyis type consists of many rotating disks. Through the spaces among the disks, hot flue gas passes on the right side, for example, while cold air flows on the left side. Heat is transferred via the rotating disks from the high-temperature exhaust gas to low temperature air. Because of its extreme compactness, this system is used in many large and medium sized boilers. Leakage is a major drawback. Leaks from the recuperator of this type used in the No. 1 to No. 3 boilers were relatively small. But for this No. 4 boiler, although the O_2 concentration at the combustion chamber outlet was low at 1.6%, the CO concentration was 1,000 ppm, and the O_2 concentration in the stack was 7%.

The NOx concentration was 170 ppm, which is the highest among the boilers in this station, despite the generation of CO. The opposed combustion mode has no flame cooling effect nor flue gas recirculation effect like the tangential combustion type, and the higher NOx concentration is considered unavoidable. The boiler was equipped with the flue gas recirculation fan to control interior temperature. Since the fan was not operated on the day of the survey, it may be another cause for the high NOx concentration.

The PM concentration of 120 mg/Nm^3 is considered to be a little too high for the fuel ratio of heavy oil at 11% and gas at 89%. The generation of a considerable amount of CO indicates the possibility of incomplete combustion resulting from insufficient air. Combustion control including installation of a recuperator is urgently needed.

5) Countermeansures

i) Retrofitting of combustion equipment

(a) Complete automatic operation with the installation of combustion control and safety control instruments

(b) Low air ratio combustion through continuous monitoring of the flue gas O_2 concentration

(c) Exhaust gas recirculation by installing flue gas blower

(d) Quasi 2-stage combustion (burner cut method) or in-furnace denitration combustion

ii) Fuel change

(a) Mixed combustion with 80% natural gas and 20% heavy oil up to the supply start of desulfurized heavy oil

(b) Mixed combustioin with 50% natural gas and 50% desulfurized heavy oil when supply of desulfurized heavy oil is started. The use of desulfurized heavy oil emulsion should be taken into consideration after thorough demonstration tests.

iii) Regular monitoring of the flue gas by installing the NOx and SO_2 telemeters

iv) When the heavy oil mixing ratio is increased over the current level, the installation of an electrostatic precipitator is desired.

6) Expenses for retrofitting of the boiler (No.4)

The existing flue gas recirculation blower will be used, and the cost will be excluded from the estimation.

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	84,600
(b)	Burner and register (3,200 l/hr) 15 units plus 4 units of sub-burner		1,557,700
(c)	Combustion control system and instrumentation	1 set	623,000
(d)	Safety control system,	1 set	467,300
(e)	On-site work supervision	1 set	69,200
(f)	On-site instruction for test operation	1 set	23,000
(g)	Package and freight	1 set	204,600
(h)	Travelling	1 set	43,000
(i)	Unexpected expenses (5% of the above)		153,620
	Sub-total		3,226,020

ii) Local portion

			(US$)
(j)	Burner and duct removal	1 set	153,800
(k)	Flue gas recirculation duct installation	1 set	443,100
(l)	Burner, duct, fan installation	1 set	123,800
(m)	Test operation and adjustment	1 set	9,200
(n)	Customs and other taxes	1 set	811,650
(o)	Warehouse, customs clearance, and land freight (incl. IVA)	1 set	63,300
(p)	Freight of duct, etc. and crane rental	1 set	13,000
(q)	IVA (15% excl. n + o)		111,400
	Sub-total		1,729,250
	Total		US$ 4,955,270

(4) Regular Monitoring of the Flue Gas by Installing NOx and SO_2 Telemeters (No.1 through No.4 boiler stacks)

Installation expenses for the flue gas telemeter

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	9,400
(b)	Instruments (SOx, NOx, O_2)	4 sets	237,200
(c)	Auxiliary units	4 sets	82,100
(d)	Data logger	1 set	17,900
(e)	On-site work supervision	1 set	8,500
(f)	Instruction for test operation	1 set	4,700
(g)	Package and freight	1 set	51,800
(h)	Travelling	1 set	12,400
(i)	Unexpected expenses (5% on above)		21,200
	Sub-total		445,200

ii) Local portion

			(US$)
(j)	Materials	1 set	8,400
(k)	Survey assistant	1 set	1,800
(l)	Installation work	1 set	8,200

m)	Test operation and adjustment	1 set	2,400
(n)	Vehicles	1 set	3,300
(o)	Customs and other taxes	1 set	92,060
(p)	Warehouse, customs clearance, land freightage, etc.	1 set	8,360
(q)	IVA (15% excl. o and p)		3,620
	Sub-total		128,140
	Total		US$ 573,340

(The expenses for telephone installation and the central receiving unit are not included.)

(5) Expenses for Installation of Electrostatic Precipitators (EP) Equipped With Ammonia Injection System

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	320,000
(b)	EP	4 sets	26,715,000
(c)	Ammonia injection system	4 sets	5,377,000
(d)	Ash disposal system	4 sets	4,980,000
(e)	Ammonia gas cylinder	100 pcs	346,000
(f)	On-site work supervision	1 set	950,000
(g)	Instruction for test operation	1 set	102,000
(h)	Package and freight	1 set	165,000
(i)	Unexpected expenses (5% on above)		1,948,000
	Sub-total		40,904,000

ii) Local portion

			(US$)
(j)	Foundation work	1 set	240,000
(k)	Installation work	1 set	7,150,000
(l)	Electric work	1 set	1,450,000
(m)	Heat insulation	1 set	3,800,000
(n)	Test operation and adjustment	1 set	125,000
(o)	Customs and other taxes	1 set	14,518,000
(p)	Warehouse, customs clearance, land freight	1 set	2,086,000

(q) IVA (15% excl. o and p)		1,915,000
(r) Interest [Foreign portion + (k+l+m+q) x $\frac{1}{2}$ + j + o + p] x 0.08		5,193,000
Sub-total		36,477,000
Total		US$ 77,381,000

(6) Reference

Installation expenses for the W/O type emulsifier
(C-class heavy oil emulsifier in Japan)
3 sets of $20m^3/hr$ unit and 1 set of $30m^3/hr$ unit

i) Foreign portion

		(US$)
(a) Design	1 set	15,400
(b) Stirrer ($20m^3/hr$)	3 sets	923,000
(c) Stirrer ($30m^3/hr$)	1 set	461,500
(d) Valve, cock, etc.	1 set	34,600
(e) On-site work instruction	1 set	15,400
(f) Test operation supervision	1 set	6,200
(g) Package and freight	1 set	42,200
(h) Travelling	1 set	22,500
(i) Unexpected expenses (5%)		76,000
Sub-total		1,596,800

ii) Local portion

		(US$)
(j) Tank	4 sets	24,600
(k) Piping	4 sets	30,800
(l) Installation work	1 set	7,700
(m) Test operation	1 set	5,400
(n) Customs and other taxes	1 set	387,400
(o) Warehouse, customs clearance, freight (incl. IVA)	1 set	32,000
(p) Crane car, fork truck, etc.		15,400
(q) IVA (15% excl. n and o)		12,600
Sub-total		515,900
Total		US$ 2,112,700

(7) Summary of Pollution Control Measures

The currently employed mixed combustion with 80% of natural gas and 20% of ordinary heavy oil is quite effective in the reduction of air pollutants from this power plant, the largest heavy oil consumer. Table 5.2.1 shows the current status and the 6 alternative control plans studied: A through F. Reference Cases (1) and (2) are also shown corresponding to 100% use of desulfurized heavy oil.

In Reference Case (1), the emissions of NOx and SO_2 increase from the present level. For reduction of the PM emission by EPs (electrostatic precipitators), installation of an ammonia injection facility is required so as to prevent corrosion of the EPs by SOx generated during combustion of the fuel which still contains sulfur at 0.8%. The investment amount required for these installations is about US$ 77 million including remodeling of the flue and the stack, and installation of an ash disposal facility. Reference Case (2) employs flue gas denitration for NOx control, flue gas desulfurization for SO_2 control, and installation of EPs for PM control. Drastic reconstructions of the boilers and flues are also required with total investment amount close to US$ 300 million.

Cases A through F employ mixed combustion of desulfurized heavy oil and natural gas. Among these alternatives, D and E are considered to be most advantageous in the NOx reduction effect and cost. However, since there are not many examples in Japan in emulsification combustion of desulfurized heavy oil, thorough demonstration tests are necessary to confirm its reduction effects and cost effectiveness as a prerequisite to the practical application. Case B brings about a large reduction in the PM emission with the same amount of investment as in Referemce Case (1).

For the period up to the start of supply of the desulfurized heavy oil, the NOx reduction measures indicated by the Note *2 in Table 5.2.1 should be implemented while maintaining the present fuel mix ratio with 80% natural gas and 20% heavy oil. In this case the reduction of the NOx emission is as follows:

NOx: 30%

Table 5.2.1 Control Measure Alternatives for Thermoelectric Power Plant (A)

		Reference (1989)*6	Present (1990)	Control Measure Alternatives A	B	C	D	E	F	Reference Case (1)	(2)
Kind of fuel used (%)	Natural gas	60	80	50	50	50	50	50	40	-	-
	Current heavy oil	40	20	-	-	-	-	-	-	-	-
	Desulfurized heavy oil	-	-	50	50	50	50	50	60	100	100
Combustion method						Emulsified combustion *1 (Winter only)	Emulsified combustion *1 (Whole year)	Emulsified combustion *1 (Whole year)	Emulsified combustion *1 (Whole year)		
Equipment improvement measure				- NOx reduction measures *2	- NOx reduction measures *2 - EP (ammonia njection)	- NOx reduction measures *2 (Emulsification by supplier)	- NOx reduction measures *2 (Emulsification by supplier)	- NOx reduction measures *3 Emulsification by the power plant)	- NOx reduction measures *2 (Emulsification by supplier)	- NOx reduction measures *2 - EP (ammonia injection)	- Flue gas desulfurization - Flue gas denitration - EP
Fuel consumption	Gas (10^6m^3/yr)	875	1,156	722	722	722	722	722	578	-	-
	Heavy oil (10^3m^3/yr)	497	252	662	662	662	662	662	794	1,324	1,324
NOx	Emission (ton/yr)	6,167	5,219	3,810	3,810	3,613	3,029	3,029	3,248	5,768	2,482
	Av. conc. (ppm)	169	143	104	104	99	83	83	89	158	68
	Assumed O_2 conc.	5%	5%	5%	5%	5%	5%	5%	5%	5%	5%
SO_2	Emission (ton/yr)	34,790	17,640	10,592	9,647	10,592	10,592	10,592	12,704	19,275	1,970
	Av. conc. (ppm)	684	347	208	190	208	208	208	250	380	39
Annual reduction ratio (%)	NOx		0	27	27	31	42	42	38	-11	52
	SO_2		0	40	45	40	40	40	28	-9	89
	PM		0	-25	87.5	-11	37.5	37.5	25	75	75
Equipment costs (1,000 US$)	NOx reduction measures			10,930	10,930	10,930	10,930	13,043	10,930	10,930	-
	EP			-	77,381 *4	-	-	-	-	77,381 *4	-
	Desulfurization			-	-	-	-	-	-	-	292,500
	Denitration			-	-	-	-	-	-	-	-
Approx. running cost (1,000 US$/yr)											
Facility depreciation (fixed for 15 yrs)				729	5,887	729	729	870	729	5,887	19,500
Interest (first 5 yrs: 8%)				874	7,065	874	874	1,043	874	7,065	23,400
Maintenance (5%) *5				547	4,416	547	547	652	547	4,416	14,625
Catalyst				-	-	-	-	-	-	-	2,459
Heavy oil			19,568	72,052	72,052	76,635	87,821	79,996	105,332	144,104	144,104
Natural gas			96,249	60,114	60,114	60,114	60,114	60,114	48,124	-	-
NH_3, $CaCO_3$			-	-	60	-	-	-	-	120	1,420
Dust disposal			-	-	126	-	-	-	-	252	252
Total (1,000US$/yr)			115,817	134,316	149,720	138,899	150,085	142,675	155,606	161,844	205,760

Note
*1. Before application of emulsified combustion of desulfurized heavy oil, thorough demonstration tests should be conducted. Ratios of pollutant emission reduction by the emulsified combustion were estimated based on the data in Japan.
*2. For No. 1- No. 4 boilers, flue gas recirculation, in-furnace denitration combustion, low air-ratio combustion, automatic operation by combustion control instruments, and monitoring of flue gas by the NOx and SO_2 telemeters, and for No. 4 boiler, installation of low-NOx burners in addition.
*3 Installation of the heavy oil emulsification unit in addition to *2.
*4 Includes installation of facilities for anmonia injection and ash disposal.
*5 Labor and power expenses are not included.
*6 Estimated based on the heavy oil consumption in 1989. When compared with this year, a large reduction of SO_2 is expected even with the Reference Case (1)

5.2.2 Thermoelectric Power Plant (B)

(1) Power Generation Boiler (No.1)

1) Specification of facility

Model	Water-tube boiler (front firing)
Capacity	154 ton/hr
Draft and ventilation	Balanced drafting
Size of furnace	$10,380^W$ x $5,800^D$ x $7,600^H$
Number and layout of burners	6 pcs for mixed combustion of heavy oil and natural gas
Furnace pressure	-2 mmAq
Ancillary facility	Air preheater (70 → 270°C)

2) Specification of burner

Model	Oil: Y-jet type Gas: Lance type
Type of fuel	Heavy oil, natural gas
Fuel consumption	i) Heavy oil : 2,600 l/hr Natural gas : 8,300 Nm^3/hr ii) Heavy oil : 6,500 l/hr Natural gas : 4,600 Nm^3/hr (Combustion rate during the analysis of flue gas)

3) Analytical data of flue gas

i) Heavy oil 20%, natural gas 80%

(Stack sampling data) 13:30/Load at 93% of rating

NOx (ppm)*	268	Particulate matter (g/Nm^3)	0.045
O_2 (%)	7.1	Flue gas temperature (°C)	170
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	2.3
CO_2 (%)	7.0		

(Emission)

	kg/hr
NOx	61
SO_2**	180
Particulate	5.8

NOx at rated operation is estimated to be 290 ppm (66 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

ii) Heavy oil 50%, natural gas 50%

(Stack sampling data) 16:00/Load at 93% of rating

NOx (ppm)*	257	Particulate matter (g/Nm^3)	0.27
O_2 (%)	7.7	Flue gas temperature (°C)	169
CO (%)	-	Combustion chamber outlet O_2 (%)	3.4
CO_2 (%)	7.4		

(Emission)

	kg/hr
NOx	59
SO_2**	440
Particulate	36

NOx at rated operation is estimated to be 290 ppm (66 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

The burners are of the mixed combustion type comprised of the steam-atomization-type heavy oil burners mounted onto the center of the lance-type gas burners.

Measurements were made for two cases, with the heavy oil and natural gas ratio of 20 : 80 and 50 : 50, respectively.

The O_2 concentration of 7.1 - 7.7% for the stack gas appeared to be too high, but it was maintained at 2.3 - 3.1% at the boiler outlet. Unexpectedly, the NOx concentration was slightly lower when the heavy oil ratio was higher. However, when the heavy oil ratio was increased to 50%, the PM emission increased to be six times greater than that of the heavy oil ratio of 20%. When the O_2 concentration at the boiler outlet was changed to 1.7 - 4.1%, it was clearly noticed that NOx emission decreased with decreasing O_2 and increased with increasing O_2. For example, the NOx concentration was around 140 ppm (as converted to 5% of O_2) at the O_2 content of 1.5 - 2.0%, and increased almost linearly to 200 ppm when the O_2 content was increased to 3.5%. Below 1.7% of O_2, however, 0.45% of CO was produced.

From the observation described above, the following conclusions can be made:

i) The increase in NOx concentration with increasing air ratio for the natural gas burner can be attributed to the fact that, for the burner not so satisfactory for mixing with air, air-fuel mixing is improved by increasing air so as to increase the combustion temperature, resulting in the increase in thermal NOx.

ii) Comparison was made between the two sets of combustion data: one for oil-gas mixing ratio of 20/80, and another for the ratio of 50/50. Usually the NOx emission amount increases in correspondence with the increase in the N content of fuel. Actually however, the NOx concentration was lower, though only slightly, in the case of the 50/50 ratio. A substantial difference as found from the comparison of these two cases is the concentration of particulate matter; 0.27 g/Nm3 for the ratio of 50/50, as compared to 0.045 g/Nm3 for the ratio of 20/80. This may be attributed primarily to the difference in the status of combustion within the furnace such as flame distribution that depends on the layout of burners for heavy oil and natural gas. Secondly, it may be due to the effects of staged combustion and flue gas recirculation resulting accidentally from unbalanced intake of air into this boiler with low combustion chamber loading.

iii) Appropriate O_2 control for the time being, and the use of flue gas recirculation or low-NOx burners and fuel change are recommended for the future.

5) Countermeasures

i) Retrofitting of combustion equipment

(a) Complete automatic operation by installing combustion control devices and safety control instruments

(b) Low air ratio combustion by regular monitoring of the fuel gas O_2

(c) Flue gas recirculation by installing the flue gas blower

(d) Installation of low NOx burners

(e) Complete retrofitting or relocation of outworn facilities

ii) Fuel change

(a) Mixed combustion with 80% natural gas and 20% heavy oil up to the supply start of desulfurized heavy oil with the suspension of the operation during the winter.

(b) Mixed combustion with of 80% natural gas and 20% desulfurized heavy oil when supply of desulfurized heavy oil is started. The use of desulfurized heavy oil emulsion should be taken into consideration after thorough demonstration tests.

iii) Regular monitoring of the flue gas by installing the NOx and SO_2 telemeters

iv) When the heavy oil mixing ratio is increased over the current level, the following conditions of this power plant should be taken into consideration for controlling pollutant emissions:

- This plant is located in the area concentrated with factories near the central part of the Mexico Valley.
- According to the result of the flue gas measurement for the boiler No.1 as described above, the amount of smoke and soot generation increased to 6 times as the heavy oil ratio increased from 20% to 50%.

Therefore, when the heavy oil ratio is increased over 20%, the following drastic measures are considered to be necessary.

(a) Total renewal of combustion equipment including the boiler itself to make better balance between boilers and burners

(b) Installation of an electrostatic precipitator equipped with an ammonia injection system

6) Expenses for combustion unit (boiler) retrofitting

Retrofitting of the boiler is to be made for introduction of flue gas recirculation, low-NOx burners, and low-O_2 combustion method.

i) Foreign Portion

			(US$)
(a)	Survey and design	1 set	38,400
(b)	Oil + gas combustion low NOx burner	6 sets	323,000
(c)	Flue gas recirculation fan	1 set	35,000
(d)	Combustion control system and instrumentation	1 set	130,000
(e)	Safety control system	1 set	97,000
(f)	On-site work supervision	1 set	23,000

g)	On-site instruction for test operation	1 set	11,500
(h)	Package and freight	1 set	37,200
(i)	Travelling	1 set	28,300
(j)	Unexpected expenses (5% on above)		36,170
	Sub-total		759,570

ii) Local portion

			(US$)
(k)	Burner removal	1 set	9,200
(l)	Flue gas recirculation duct fabrication	1 set	70,000
(m)	Burner, duct, fan installation (incl. fuel piping modification work)	1 set	17,000
(n)	Test operation and adjustment	1 set	5,800
(o)	Customs and other taxes	1 set	170,600
(p)	Warehouse, customs clearance, land freight (incl. IVA)	1 set	12,900
(q)	Duct, etc. freightage and crane rental	1 set	5,000
(r)	IVA (15% excl. o + p)		16,000
	Sub-total		306,500
	Total		US$ 1,066,070

7) Reduction Ratio

NOx: 49% (37%)

SO_2: 79% (79%)

PM: 46% (17%)

The reduction ratio indicated by the parentheses corresponds to that for emulsified combustion during the winter only.

(2) Power Generation Boiler (No.2)

1) Specification of facility

Model	Water-tube boiler (front firing)
Capacity	150 ton/hr
Draft and ventilation	Balanced drafting
Size of furnace	$10{,}380^W \times 5{,}800^D \times 7{,}600^H$
Number and layout of burner	6 pcs for mixed combustion of heavy oil and natural gas

Furnace pressure	-2.5 mmAq
Ancillary facility	Air preheater (80 → 275°C)

2) Specification of burner

Model	Oil: Y-jet type, Gas: Lance type
Type of fuel	Heavy oil, natural gas
Fuel consumption	i) Heavy oil: 2,400 l/hr, Natural gas: 10,600 Nm^3/hr ii) Heavy oil: 6,000 l/hr, Natural gas: 6,990 Nm^3/hr (Combustion rate during the analysis of flue gas)
Fuel pressure	Unknown
Atomizing pressure	Unknown

3) Analytical data of flue gas

i) Heavy oil 20%, natural gas 80%

(Stack sampling data) 14:00/Load at 93% of rating

NOx (ppm)*	169	Particulate matter (g/Nm^3)	0.025
O_2 (%)	5.1	Flue gas temperature (°C)	185
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	1.3
CO_2 (%)	8.6		

(Emission)

	kg/hr
NOx	58
SO_2**	160
Particulate	4.2

NOx at rated operation is estimated to be 178 ppm (61 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

ii) Heavy oil 50%, natural gas 50%

(Stack sampling data) 16:00/Load at 93% of rating

NOx (ppm)*	191	Particulate matter (g/Nm^3)	–
O_2 (%)	6.3	Flue gas temperature (°C)	191
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	4.0
CO_2 (%)	9.3		

(Emission)

	kg/hr
NOx	59
SO_2**	440
Particulate	–

NOx at rateed operation is estimated to be 205 ppm (63 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

It appeared for this boiler that the NOx concentration increased slightly when the heavy oil ratio was increased from 20% to 80%. This increase is considered due to the increase in the O_2 content from 1.3% to 4.0% along with the increase in the heavy oil ratio.

5) Countermeasures

The same as for No.1 boiler.

6) Expenses

The same as for No.1 boiler: US$ 1,066,070

7) Reduction ratio

The same as for No.1 boiler.

NOx : 49% (37%)

SO_2 : 79% (79%)

PM : 46% (17%)

The reduction ratio indicated by the parentheses corresponds to that for emulsified combustion during the winter only.

(3) Power Generation Boiler (No.3 and No.4)

1) Specification of facility

Model	Water-tube boiler (tangential firing)
Capacity	350 ton/hr
Draft and ventilation	Balanced drafting
Number of burners	Heavy oil: 12 pcs, Gas: 24 pcs (total 36)
Ancillary facility	Air preheater (70 → 260°C)

2) Specification of burner

Model	Oil: Y-jet type, Gas: Lance type
Type of fuel	Heavy oil, natural gas
Fuel consumption	Heavy oil: 2,200 l/hr, Gas : 978 Nm^3/hr (for each burner)
Atomizing steam pressure	8 kg/cm^2g

3) *Analytical data of flue gas*

Measurement was not possible because these boilers were not operated.

4) Countermeasures

i) Retrofitting of combustion equipment

(a) Complete automatic operation by installing combustion control devices and safety control instrumentation.

(b) Low air ratio combustion by regular monitoring of the fule gas O_2

(c) Flue gas recirculation by installing the flue gas blower

(d) Quasi 2-stage combustion (burner cut method) or in-furnace denitration combustion

ii) Fuel change

(a) Mixed combustion with 80% natural gas and 20% heavy oil up to the supply start of desulfurized heavy oil

(b) Mixed combustioin with 50% natural gas and 50% desulfurized heavy oil when supply of desulfurized heavy oil is started. Emulsification of desulfurized heavy oil should be taken into consideration after thorough demonstration tests.

iii) Regular monitoring of the flue gas by installing the NOx and SO_2 telemeters

iv) When the heavy oil mixing ratio is increased over the current level, the installation of electrostatic precipitators equipped with an ammonia injection system is desired.

5) Expense for combustion facility (boiler) retrofitting

	(US$)
i) Foreign portion	906,000
ii) Local portion	815,000
Sub-total	1,721,000

Total: Above amount x 2 (No.3 , No.4) US$ 3,442,000
(Estimated from the expenses for the No.1 and No.2 boilers)

6) Reduction ratio (Common to No.3 and No.4 boiler)

NOx: 57% (43%)

SO_2: 79% (79%)

PM: 46% (17%)

( ) indicates the reduction ratio when emulsified combustion of desulfurized heavy oil is applied only during the winter.

(4) Summary for No.1 - No.4 Boilers

1) Total retrofitting expenses US4 5,574,140

2) Average reduction ratio for No.1 - No.4 boilers

NOx: 54% (41%)

SO_2: 79% (79%)

PM: 46% (17%)

(5) Expenses for Installation of the NOx, SO_2 Telemeter

To be installed on the stacks of No.1 through No.4 boilers.

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	9,400
(b)	NOx, SOx, O_2 meters	4 sets	237,200
(c)	Auxiliary units	4 sets	82,100
(d)	Data logger	1 set	17,900
(e)	On-site work supervision	1 set	8,500
(f)	On-site instruction for test operation	1 set	4,700
(g)	Package and freight	1 set	51,800
(h)	Travelling	1 set	12,400
(i)	Unexpected expenses (5% on above)		21,200
	Sub-total		445,200

ii) Local portion

		(US$)
(j) Materials	1 set	8,400
(k) Survey assistant	1 set	1,800
(l) Installation expenses	1 set	8,200
(m) Test operation and adjustment	1 set	2,400
(n) Vehicles	1 set	3,300
(o) Customs and other taxes	1 set	92,060
(p) Warehouse, customs clearance, land freight (incl. IVA)	1 set	8,360
(q) IVA (15% excl. o and p)		3,620
Sub-total		128,140
Total		US$ 573,340

(The expenses for telephone installation and the central receiving unit are not included.)

(6) Reference

Installation expenses of the W/O type emulsifier
(C-class heavy oil emulsifier in Japan)
4 sets of 2.4m^3/hr unit

i) Foreign portion

		(US$)
(a) Design	1 set	15,400
(b) Stirrer (2.4m^3/hr)	4 sets	346,000
(c) Valve, cock, etc.	1 set	20,000
(d) On-site work supervision	1 set	11,500
(e) Package and freight	1 set	19,200
(f) Travelling	1 set	18,400
(g) Unexpected expenses (5%)		21,500
Sub-total		452,000

ii) Local portion

		(US$)
(h) Tank	4 sets	6,150
(i) Piping	4 sets	15,400
(j) Installation work	1 set	7,700

(k)	Test operation	1 set	5,400
(l)	Customs and other taxes	1 set	120,800
(m)	Warehouse, customs clearance, freight (encl. IVA)	1 set	10,200
(n)	Crane car, fork truck, etc.	1 set	6,500
(o)	IVA (15% excl. l and m)		6,170
	Sub-total		178,320
	Total		US$ 630,320

(7) Summary of Pollution Control Measures (No.1 - No.4 boilers)

Table 5.2.2 summarizes the pollution control measures for the Thermoelectric Power Plant (B).

Table 5.2.2 Summary of Pollution Control Measures for the Thermoelectric Power Plant (B)

		Current status	Countermeasures	
Fuel type		Natural gas 80% Heavy oil 20%	Natural gas 80% Desulfurized heavy oil 20%	
Combustion system		-	Emulsified Combustion	
			Alternative A	Alternative B
			Winter only	Whole year
Fuel consumption	Gas ($10^6 m^3/hr$)	211.4	211.4	211.4
	Heavy oil ($10^3 m^3/hr$)	48.7	48.7	48.7
Emission (ton/yr)	NOx	1,044	616	480
	SO_2	3,409	725	725
Reduction ratio (%)	NOx		41	54
	SO_2		79	79
	PM		17	46
Equipment Cost (1,000 US$)	Retrofit, etc.		5,574.14	5,574.14
	NOx, SO_2, telemeter		573.34	573.34
Running cost (approx.) (1,000 US$)				
Facility depreciation (15 yr)			410	410
Interest (first 5 yrs: 8%)			492	492
Maintenance cost (5%)			307	307
Heavy oil		3,782	5,564	7,381
Natural gas		17,601	17,601	17,601
Total	(1,000US$/yr)	21,377	24,374	26,191

Note 1. The costs do not include labor and power expenses.

2. Alternative A is for the case of one month shutdown for periodical repair and the 2.5-month period of emulsion combustion during the winter of 3.5 months, and direct combustion of desulfurized heavy oil for the remaining period of the year. The reduction ratio is for annual average.

3. Alternative B is for the case of the emulsified combustion throughout the year.

4. Emulsified combustion of desulfurized heavy oil should be employed after confirmation of its effect and cost through an adequate feasibility study.

5. The reduction ratio by emulsified combustion was estimated from the actual reduction in Japan.

5.2.3 Petroleum Refinery

(1) Oil Heating Furnaces

1) Name of facility surveyed   Oil heating furnaces as shown below

2) Principal measurement data

Name of Furnace	Input (Mcal/hr)	Outlet temperature of heated object (°C)	Temperature of convection section (°C)	Flue gas temperature (°C)	NOx (ppm)	O_2 (%)	Combustion chamber load ($Mcal/m^3hr$)
AA-F1, F2	51,600	174/346	612	555	92	5.5	7.7
AA-F3	2,967 ~ 8,516	175/345	550	400	61	6.8	6.3
RV-H1	132,698	204/394	465 477	384	59	6.9	2.0
AW-H1	4,600	223/401	599	610	60	2.2	4.3
RE-H10	11,300	410/445	Unknown	420	54	13.0	1.2
AR-H1 AU-H1	18,400 2,300	168/211 308/320	Unknown Unknown	375	42	9.6	17.0 3.1
AQ-H1	6,000	270/326	421	418	79	10.9	2.1

3) Observation

These are box-type heating furnaces using the medium-pressure Bunsen burners for natural gas. Upward firing system is basically employed with some downward burners also incorporated. It is designed for sufficient distance between the flame and the tubes to be heated to prevent overheating of the oil tubes and to facilitate heating with radiated heat from the refractories. Accordingly, the combustion chamber is wide enough and the combustion chamber loading is low. Natural drafting is employed, and sufficient stack draft is secured. The air ratio is manually adjusted with dampers provided in the horizontal flue.

The O_2 content during operation was normally 6 - 7%, but O_2 contents of around 2% and 10 - 12% were also observed. The simple average of measured NOx concentration values was 64 ppm as converted to 5% O_2. The NOx concentration level is normal for boilers applied with NOx reduction measures. As a result of reducing the O_2 content by around 2% by adjusting the dampers, the converted NO_x concentration showed an upward trend with decrease in the air ratio. But such increase was as small as around 3 ppm. This low-NOx characteristic is considered due to self-recirculation caused by the induction effect of flame jet because the flame of the medium-pressure Bunsen burner is blown into the furnace filled with CO_2 with low combustion chamber loading such as the case of open combustion. Differences in the NOx concentration among furnaces may be attributed to differences in the situation of contact of the flame and the brick wall.

In terms of efficiency, on the other hand, the temperature difference between the heated oil and the flue gas ranged from 200°C to nearly zero, indicating wide disparities in heating efficiency among furnaces. An attempt was made to determine the efficiency of oil heating from the fuel input, but it was impossible because there were almost no reliable and satisfactory measuring instruments installed. It is essential for future improvement of equipment and operation of these facilities to install measuring instruments for the flow rate, the temperature of the heated oil, the flow rate of fuel, and the O_2% and the NOx concentration of the flue gas. *Determination and maintenance of the appropriate operational conditions* with less emission of air pollutants, using these instruments, are crucial. Moreover, reduction of NOx concentration by around 40% can be expected by installing the forced-draft-type low-NOx burners.

4) Countermeasures (Common to all of the oil heating furnaces)

Automatic operation control by installing a complete set of instrumentation: flowrates of heating object and fuel, temperature and O_2, etc.

5) Expenses

A total of about US$1,000,000 for the 12 heating furnaces with US$75,000 - 93,000 for each furnace for installation of the following:

- damper controller
- air-ratio adjuster
- gas flow meter
- Air flow meter
- controller panel

6) Reduction Ratio

Reductions in NOx, PM and fuel consumption by means of the low air-ratio combustion with the flue gas O_2 content of 3.5% are expected as follows:

Furnace	Reduction ratio (%) NOx	Fuel
AA-F1, F2	16	4
AA-F3	23	4
RV-H1	23	4
AW-H1	-	-
RE-H10	41	20
AR-H1, AU-H1	36	10
AQ-H1	40	15

(2) Power Generation Boiler (G1, G2, G3 and G4)

1) Specification of facility — (Four boilers are in the same specification, but the measurement was not made on No.4 boiler.)

Model	Water-tube drum boiler
Capacity	55 ton/hr
Draft and ventilation	Balanced draft
Size of furnace	$5{,}500^W \times 5{,}000^D \times 60{,}000^H$
Number and layout of burner	Oil/gas mixed combustion burner, 4 per boiler
Furnace pressure	-5 mmAq
Ancillary facility	Air preheater (30 → 250°C)

2) Specification of burner

Model	Gas: ring type, Oil: Y-jet type
Type of fuel	Natural gas and heavy oil
Fuel consumption	Natural gas : 5,485 Nm^3/hr
	Heavy oil : 4,640 l/hr
Fuel pressure	Natural gas : 1 kg/cm^2g,
	Heavy oil : 6 kg/cm^2g
Atomizing pressure	Steam : 5 kg/cm^2g

3) Analytical data of flue gas

i) G1 boiler (gas 91%, heavy oil 9%)

(Stack sampling data) 12:30/Load is approx. 92% of rating

NOx (ppm)*	143	Particulate matter (g/Nm^3)	0.09
O_2 (%)	5.1	Flue gas temperature (°C)	232
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	4.1
CO_2 (%)	8.4		

(Emission)

	kg/hr
NOx	19
SO_2**	36
Particulate	5.7

NOx at rated operation is estimated to be 145 ppm (20 kg/hr).

* Converted to oxygen concentration of 5%.

** Calculated from analytical value of fuel

ii) G1 boiler (gas 100%, heavy oil 0%)

(Stack sampling data) 14:30/Load is approx. 92% of rating

NOx (ppm)*	136	Particulate matter (g/Nm^3)	0.016
O_2 (%)	5.1	Flue gas temperature (°C)	237
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	4.0
CO_2 (%)	8.6		

(Emission)

	kg/hr
NOx	17
SO_2**	- -
Particulate	0.98

NOx at rated operation is estimated to be 140 ppm (18.5 kg/h).

* Converted to oxygen concentration of 5%.

** Calculated from analytical value of fuel

iii) G2 boiler (gas 60%, heavy oil 40%)

(Stack sampling data) 14:30/Load is approx. 76% of rating

NOx (ppm)*	109	Particulate matter (g/Nm^3)	0.006
O_2 (%)	4.6	Flue gas temperature (°C)	217
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	4.1
CO_2 (%)	8.5		

(Emission)

	kg/hr
NOx	6.8
SO_2**	94
Particulate	0.18

NOx at rated operation is estimated to be 115 ppm (9.4 kg/h).

* Converted to oxygen concentration of 5%.

** Calculated from analytical value of fuel

iv) G3 boiler (gas 81%, heavy oil 19%)

(Stack sampling data) 12:30/Load is approx. 24% of rating

NOx (ppm)*	75	Particulate matter (g/Nm^3)	0.0071
O_2 (%)	10.5	Flue gas temperature (°C)	242
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	9.3
CO_2 (%)	5.7		

(Emission)

	kg/hr
NOx	4.0
SO_2**	24
Particulate	0.28

NOx at rated operation is estimated to be 120 ppm (25 kg/h).

* Converted to oxygen concentration of 5%.

** Calculated from analytical value of fuel

4) Observation

These power generation boilers of the refinery are about 50 years old. They are rated at 75 ton/hr at ordinary altitudes. But since the Mexico City is located at 2,300 m above sea level, they are operated at the rate of 55 ton/hr. The four boilers, G1 through G4, are of the same type and size; one of them is alternately out of service for maintenance. The low-NOx burners offered from the Government of Japan have been installed in the G3 boiler. The operation of this low-NOx burner is reported in the Appendix. The data for these power generation boilers can be used interchangeably.

Although the flue gas analysis data show the low concentration of particulate matter, smoke emissions from the stacks were often observed. A long period of sampling (1 day) might have given higher levels of the PM concentration. The sporadic smoking is due to remote manual control of the boilers in the absence of automation. For example, the fuel flow rate and the combustion air flow rate are controlled by separate remote levers, the feedwater flow rate and the steam generation rate are controlled by separate remote levers, and the operator must therefore rely on his eyes by watching the water level indication on the drum. In such a system, quite understandably, slight faults would cause smoking.

The NOx emission data are normal for a natural gas boiler. If the O_2 content is reduced, the NOx emission can be reduced. However, as long as the manual control is left in use, no reduction of NOx and particulate matter is considered possible.

5) Countermeasures

i) Retrofitting of combustion equipment

(a) Automatic operation control by installation of measuring instruments: steam pressure, steam generation rate, temperature, fuel flowrate, flue gas O_2, etc.
(b) Continuous monitoring of flame by the flame-eye and safety measures for emergency such as automatic breaker
(c) Exhaust gas recirculation by installing a recirculation fan and installation of low-NOx burners

ii) Fuel change

Natural gas should be used exclusively.

iii) Regular monitoring of the flue gas by installing the NOx telemeter

(3) Power Generation Boiler (G5)

1) Specification of facility

Model	Water-tube boiler
Capacity	120 ton/hr
Draft and ventilation	Balanced drafting
Number of burners	6 units (gas and oil mixed burning)
Furnace pressure	-10 mmAq
Ancillary facility	Air preheater (30 → 250°C)

2) Specification of burner

Model	Gas: Lance type, Oil: Steam atomization type
Type of fuel	Natural gas & heavy oil
Fuel consumption	Gas: 11,680 Nm^3/hr, Oil: 9,930 l/hr
Fuel pressure	Gas: 0.2 kg/cm^2g, Oil: 8.2 kg/cm^2g

3) Analytical data of flue gas

(Stack sampling data) 13:00/Load at 75% of rating

NOx (ppm)*	124	Particulate matter (g/Nm^3)	0.051
O_2 (%)	5.5	Flue gas temperature (°C)	220
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	3.0
CO_2 (%)	8.6		

(Emission)

	kg/hr
NOx	22
SO_2**	69
Particulate	4.6

NOx at rated operation is estimated to be 160 ppm (28 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

Five boilers are connected with a steam header loop and the steam is supplied to four bleeding turbines to be used for power generation and for other processes. A recuperator is provided and drafting is made with a forced draft fan and an induced draft fan.

The system is designed with sufficient margin so that the combustion chamber loading can be low. Accordingly, the current NOx concentration is not so high. The analytical value of O_2 after the recuperator was high because of air leak-in from the recuperator. Practical measures to reduce NOx include the use of low-NOx burners and flue gas recirculation.

5) Countermeasures

Same as for G1 and G2 boilers.

(4) Packaged Power Generation Boiler (CP)

1) Specification of facility

Model	CP water-tube boiler
Capacity	55 ton/hr
Draft and ventilation	Forced draft
Structure and size of furnace	$2{,}100^W$ x $7{,}400^D$ x $2{,}400^H$
Number and layout of burner	2 units (gas and heavy oil mixed burning)
Furnace pressure	+80 mmAq
Ancillary facility	None

2) Specification of burner

Model	Gas:	Heavy Oil:
Type of fuel	Natural gas & heavy oil	
Fuel consumption	Gas: 4,000 Nm^3/hr, Heavy Oil: 3,400 l/hr	
Fuel pressure	0.33 kg/cm^2g	

3) Analytical data of flue gas

(Stack sampling data) 14:00/Load at 53% of rating

NOx (ppm)*	85	Particulate matter (g/Nm^3)	<0.0002
O_2 (%)	1.3	Flue gas temperature (°C)	282
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	1.3
CO_2 (%)	11.5		

(Emission)

	kg/hr
NOx	7.1
SO_2**	29
Particulate	<0.0066

NOx at rated operation is estimated to be 160 ppm (13.0 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

Five boilers are connected with steam header loop and steam supplied to four bleeding turbines is used for power generation and process steam.

These water-tube type package boilers, made by Babcock & Wilcox, were installed in 1981 and have no recuperator. They are equipped with the heavy oil and gas mixed type burners and are operated currently for mixed combustion.

Possibly due to mixed combustion, the NOx concentration was lower than expected. The NOx emission may be reduced further by using the low-NOx burners or flue gas recirculation.

5) Countermeasures

Same as for G1, G2 and G5 boilers.

(5) Expenses for Control Measures for Boilers (G1 - G5 and CP)

Retrofitting of equipment for introduction of low-NOx burners, flue gas recirculation, and low-O_2 combustion with full automatic operation.

i) Foreign portion

		G1, G2 (US$)	G5 (US$)	CP (US$)
(a) Survey and design	1 set	7,700	7,700	7,700

			G1, G2	G5	CP
(b)	Low NOx burner		212,300	323,000	138,500
	G1, G2: 1,200 l/hr	4 sets			
	G5: 1,700 l/hr	6 sets			
	CP: 1,800 l/hr	2 sets			
(c)	Flue gas recirculation fan	1 set	22,300	27,000	14,600
(d)	Combustion control instrumentation and electric system	1 set	62,000	88,000	62,000
(e)	On-site work supervision	1 set	23,000	23,000	23,000
(f)	On-site instruction for test operation	1 set	7,700	7,700	7,700
(g)	Package and freight	1 set	32,500	42,500	20,000
(h)	Travelling	1 set	12,600	12,600	12,600
(i)	Unexpected expenses (5% of above)		19,000	26,600	14,300
	Sub-total		399,100	558,100	300,400

ii) Local portion

			(US$)	(US$)	(US$)
(j)	Burner removal	1 set	1,500	2,000	1,000
(k)	Flue gas recirculation duct fabrication	1 set	27,000	54,000	26,000
(l)	Burner duct, fan installation	1 set	6,900	13,000	6,900
(m)	Test operation and adjustment	1 set	2,300	3,500	2,300
(n)	Customs and other taxes	1 set	93,100	138,000	66,000
(o)	Warehouse, customs clearance, land freight (incl. IVA)	1 set	8,820	11,900	5,840
(p)	IVA (15% excl. n + o)		5,600	10,900	5,400
	Sub-total		145,220	233,300	114,040
	Total		US$ 544,320	791,400	414,440

iii) Total expense for control measures for boilers (G1 - G5 and CP)

		(US$)
G1 and G2	544,320 x 2 =	1,088,640
G3 and G4	93,000 x 2 =	186,000
G5		791,400
PC		414,440
Total		US$ 2,480,480

Note: Installation of low-NOx burners is completed in G3 boiler, and the installation has been already planned for G4 boiler. Therefore, costs of low-NOx burners are excluded for these two boilers.

(6) Reduction Ratio for Boilers

	G1 - G5 Boilers	CP Boiler
NOx	67%	55%
SO_2	100%	100%
PM	20%	20%

Note: Above estimation corresponds to the case when the O_2 content of the flue gas is controlled at 3.5%.

(7) Expenses for Installation of Telemeter System for Monitoring Flue Gas

1) Boilers (G1 - G5 and CP)

NOx and O_2 meters to be installed on G1 to G5 and CP boilers.

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	9,400
(b)	NOx, O_2 instrumentation	6 sets	205,900
(c)	Auxiliary units	6 sets	116,880
(d)	Data logger	1 set	17,800
(e)	Local work on-site supervision	1 set	17,000
(f)	On-site instruction for test operation	1 set	4,700
(g)	Package and freight	1 set	77,000
(h)	Travelling	1 set	15,700
(i)	Unexpected expenses (5% of the above)		23,220
	Sub-total		487,620

ii) Local portion

			(US$)
(j)	Materials	1 set	9,600
(k)	Survey assistant	1 set	1.200
(l)	Installation expenses	1 set	15,300
(m)	Test operation and adjustment	1 set	2,100
(n)	Vehicle rental	1 set	4,500
(o)	Customs and other taxes	1 set	93,000

(p)	Warehouse, customs clearance, and land freight (incl. IVA)	1 set	8,400
(q)	IVA (15% excl. o and p)		4,900
	Sub-total		139,000
	Total		US$ 626,620

Note: Telephone installation work and central reception system are not included.

2) Oil heating furnaces

When hydrogen sulfide is burned without recovery by an amine reactor, SO_2, NOx, and O_2 meters are to be installed in RE-H9 and RE-H10 furnaces.

i) Foreign portion

			(US$)
(a)	Survey and design expenses	1 set	5,700
(b)	SO_2 NOx, O_2 instrumentation	1 set	118,560
(c)	Auxiliary units	1 set	44,160
(d)	Data logger	1 set	17,800
(e)	Local work on-site supervision	1 set	10,800
(f)	On-site instruction for test operation	1 set	4,700
(g)	Package and freight	1 set	26,000
(h)	Travelling	1 set	12,800
(i)	Unexpected expenses (5% of the above)		12,000
	Sub-total		252,520

ii) Local portion

			(US$)
(j)	Materials	1 set	4,800
(k)	Survey assistant	1 set	1,000
(l)	Installation expenses	1 set	4,400
(m)	Test operation and adjustment	1 set	1,600
(n)	Vehicle rental	1 set	2,200
(o)	Customs and other taxes	1 set	49,000
(p)	Warehouse, customs clearance, and land freight (incl. IVA)	1 set	4,000
(q)	IVA (15% excl. o and p)		2,100
	Sub-total		69,100
	Total		US$ 321,620

3) Sulfur recovery plant and FCC plant

H_2S, SO_2 and O_2 meters are to be installed in the sulfur recovery plant and FCC plant.

	(US$)
i) Foreign portion	220,000
ii) Local portion	56,000
Total	US$ 276,000

(8) Control Measures for Other Facilities

1) SO_2 Emissions From Non-combustion Processes

i) Current status and control plan of PEMEX

According to the report of PEMEX submitted to SEDUE in January 1991, the current status and the remedial measures on the sulfur emission from the sulfur recovery plant in the refinery are as follows.

Current status in SO_2 emission is as follows:

Emission from the sulfur plant	6.580	ton/day
Vis-breaker heating furnace (2 units) 2 x 7.607 =	15.214	ton/day
Vent gas	7.274	ton/day
F.C.C.	5.279	ton/day
Others	0.124	ton/day
Total	34.471	ton/day

Control measures planned by PEMEX are as follows:

(a) Sulfur plant modernization

(b) Capacity expansion of the sulfur recovery plant

(c) Efficiency improvement of heat recovery and heat exchange

With the above measures, the emission will be reduced by 11.751 ton/day, but 22.72 ton/day will be still emitted.

Since nearly a half of the sulfur contents of crude oil is converted into H_2S through the various refining processes in refineries, exhaust gases usually contain much H_2S. This H_2S is usually further oxidized into free sulfur as follows:

$$H_2S + 3/2\ O_2 \rightarrow H_2O + SO_2$$
$$2H_2S + SO_2 \rightarrow 2H_2O + 3S$$

$$3H_2S + 3/2\ O_2 \rightarrow 3H_2O + 3S$$

The sulfur recovery process based on the above reaction is known as the Claus method. Earlier, single stage reactors with a recovery ratio of 80 to 85% were in use, but later, the 2-stage reactors with a recovery ratio of 90 to 94% were introduced. And now, 3-stage reactors with a recovery ratio of 95 to 98% are in use, reducing S in the tail gas. At this Refinery, one Claus reactor (nominal recovery ratio: 88%) is in use to recover the sulfur in the discharge gas from F.C.C. (catalyst cracking unit). To increase the recovery ratio to 94%, the installation of the second Claus reactor (40 t S/d) is under plan. However, even though the plan is realized, 94% recovery means that 6% of sulfur (or 5.1 ton/day of SO_2) will be discharged in the tail gas.

ii) Control measures proposed in this Study

In all the refineries in Japan, the tail gas is further treated to an overall recovery ratio of 97 to 98% through such measures as: 1) TGT (tail gas treater: Scott process) for recirculating the tail gas after H_2S removal, and 2) the coal-gypsum desulfurization process.

A. Sulfur recovery

In the present case, the input to the scheduled 40 ton/day sulfur recovery plant is proposed to be as follows:

(a) H_2S being sent to the existing recovery plant: 22 ton/day as S

(b) H_2S in the exhaust gas from the above plant: 6.580 ton/day as SO_2

(c) H_2S in the visbreaker exhaust gas: 2 x 7.607 ton/day as SO_2

(d) 90% of Vent gas sulfur: 0.9 x 7.274 ton/day as SO_2

The amount to be recovered as S is
22 + (6.58 + 2 x 7.607 + 0.9 x 7.274)/2 = 36.17 ton/day

B. Installation of amine unit

To recovery H_2S from the visbreaker exhaust gas for transfer to the above sulfur plant, installation of an amine unit (approx. US$3,000,000) is required. It should be noted that the absorption ratio at high H_2S concentration is over 90%, but at low concentration, the recovery ratio is very low.

C. Installation of flue gas desulfurizer

The SO_2 in the exhaust from the new sulfur plant and 10% of SO_2 in the vent gas will be removed by a flue gas desulfurizer.

Required capacity of the desulfurizer is:

(a)	Sulfur plant outlet	5.100 ton/day
(b)	F.C.C.	5.279 ton/day
(c)	Vent gas	0.1 x 7.274 = 0.727 ton/day
	Total	11.106 ton/day

When 95% of the above amount of SO_2 is removed as $CaSO_4$, the construction cost will be US$16,000,000, excluding construction of the duct blower from the above amine unit, vent gas recovery unit, sulfur recovery plant, F.C.C. and vent gas.

No other exhaust gas will be treated.

iii) SO_2 reduction achieved by the above measures.

SO_2 emission:

$$34.471 - (2x7.607x0.9 + 5.279 + 6.580 + 7.274x0.9) + 11.106 \times 0.05 = 2.928 \text{ ton/day}$$

Reduction ratio:

$$(34.471 - 2.928) \times 100 / 34.471 = 91.5\%$$

2) Other pollutant emissions

According to the data from the refinery, emissions of HC, CO and NOx are as follows:

HC:	28.957	ton/day
CO:	147.447	ton/day
NOx:	10.671	ton/day

To control these pollutants, the refinery has the plan of installing floating roofs on the tanks to control HC emission and to start rehabilitation works for the CO boiler in April, earlier than scheduled, to burn CO as before.

(9) Summary of Expenses

		(US$)
1)	Sulfur recovery plant modernization and new installation	9,100,000
2)	Installation of the fuel tank floating roofs for HC evaporation control	1,600,000
3)	Installation of the amine unit for H_2S recovery from the visbreaker exhaust gas	3,000,000
4)	Installation of the flue gas desulfurizer	16,000,000
5)	Installation of the NOx, O_2 telemeters on boilers (G1 - G5 and CP boilers)	626,620
6)	Installation of the SO_2 , NOx, O_2 telemeters on furnaces (RE-H9 and RE-H10)	321,620
7)	Installation of the H_2S, SO_2, O_2 telemeter on the sulfur plant and the FCC plant	276,000
8)	Full automatic control of the oil heating furnaces	1,000,000
9)	Total expense for retrofitting of G1 to G5 and PC boilers	2,480,480
	Total	US$ 34,404,720

5.2.4 Chemical Products Factory (A)

(1) Boiler for Processing (D and E)

1) Specification of facility

Model	Water tube boiler
Capacity	5 ton/hr (D boiler), 15 ton/hr (E boiler)
Draft and ventilation	*Forced draft*
Dimensions of boilers	$1{,}600^W \times 2{,}200^D \times 1{,}400^H$ (D boiler) $2{,}300^W \times 3{,}200^D \times 2{,}100^H$ (E boiler)
Number of burners	1 each (D and E boilers)
Furnace pressure	+60 mmAq (D boiler) +20 mmAq (E boiler)
Ancillary facility	None

2) Specification of burner

Model	Lance type gas burner
Type of fuel	Natural gas
Fuel consumption	750 Nm^3/hr (D boiler) 1,500 Nm^3/hr (E boiler)
Fuel pressure	1 kg/cm^2g (D and E boilers)

3) Analytical data of flue gas

i) D boiler

(Stack sampling data) 17:00/Load is approx. 60% of rating

NOx (ppm)*	24	Particulate matter (g/Nm^3)	0.0015
O_2 (%)	0.9	Flue gas temperature (°C)	267
CO (%)	0.70	Combustion chamber outlet O_2 (%)	0.9
CO_2 (%)	10.9		

(Emission)

	kg/hr
NOx	0.28
SO_2**	–
Particulate	0.0069

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

ii) E boiler

(Stack sampling data) 13:00/Load is approx. 67% of rating

NOx (ppm)*	62	Particulate matter (g/Nm^3)	0.0009
O_2 (%)	4.1	Flue gas temperature (°C)	253
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	4.1
CO_2 (%)	9.3		

(Emission)

	kg/hr
NOx	1.7
SO_2**	–
Particulate	0.011

NOx at rated operation is estimated to be 67 ppm (2.7 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

Soap is manufactured at this plant.

Natural gas is used as the fuel for combustion in this plant. The fuel consumption of these boilers is considerably larger than that of the heat medium boilers or dryers. There are 5 boilers used in the heating process in soap manufacture. In the diagnostic survey, flue gas analyses were carried out for two boilers, namely the 5 ton/hr boiler (D boiler) and 15 ton/hr boiler (E boiler).

In the D boiler, the NOx concentration was as low as 24 ppm. This is believed to be due to the low concentration of O_2 at 0.9% and the high concentration of CO at 7,000 ppm. In other words, combustion control of this boiler is not adequate.

These boilers are automated, and loading can be automatically changed when necessary. Since these boilers use natural gas, there are no special problems other than inadequate combustion control.

5) Countermeasures

Low air ratio combustion through continuous monitoring of the flue gas O_2 is required. Since the NOx concentration is at a satisfactory level because of use of natural gas, installation of a telemetric monitoring system for the flue gas is not considered to be necessary.

6) Expenses

Portable O_2 meter	1 set	US$ 2,400
		(to be used in common with other facilities)

The above cost does not include the customs duty, customs clearance and domestic freight.

7) Reduction ratio

NOx: Some reduction

PM: Some increase will take place when the low air ratio combustion is started, but because the present emission is close to zero, a slight increase will be practically harmless.

CO: Through adequate combustion control, a 100% reduction is expected.

(2) Heat Medium Boilers (No.100 and No.300)

1) Specification of facility

Model	One through pass type heat medium boiler (bottom firing)
Capacity	1 x 10^6 kcal/hr (No. 100) 3 x 10^6 kcal/hr (No. 300)
Draft and ventilation	Forced draft
Dimensions of boilers	$1{,}100^{\varnothing}$ x $1{,}800^{H}$ (No. 100) $1{,}570^{\varnothing}$ x $2{,}695^{H}$ (No. 300)
Number of burners	1 burner each (No. 100 and No. 300)
Furnace pressure	+20 mmAq (No. 100), Estimated +20 mmAq (No. 300), Estimated
Ancillary facility	None

2) Specification of burner

Model	Nozzle mix type gas burner
Type of fuel	Natural gas
Fuel consumption	105 Nm^3/hr (No. 100) 313 Nm^3/hr (No. 300)
Fuel pressure	200 mmAq (No. 100 and No. 300)

3) Analytical data of flue gas

i) No. 100 boiler

(Stack sampling data) 14:00/Load is approx. 100% of rating

NOx (ppm)*	68	Particulate matter (g/Nm^3)	<0.0004
O_2 (%)	4.9	Flue gas temperature (°C)	198
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	–
CO_2 (%)	7.3		

(Emission)

	kg/hr
NOx	0.20
SO_2**	–
Particulate	<0.0006

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

ii) No. 300 boiler

(Stack sampling data) 12:00/Load is approx. 100% of rating

NOx (ppm)*	112	Particulate matter (g/Nm^3)	<0.0004
O_2 (%)	7.8	Flue gas temperature (°C)	170
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	-
CO_2 (%)	7.1		

(Emission)

	kg/hr
NOx	0.70
SO_2**	–
Particulate	<0.0015

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

There are 5 heat medium boilers, and they are used in the heating process in soap manufacture. In the diagnostic survey, flue gas analyses were carried out for 2 boilers, namely the 1 million kcal/hr boiler (No.100) and the 3 million kcal/hr boiler (No.300).

The heating medium flows through the tube in these boilers, and the heat of combustion gas is transferred to the heating medium through the tube walls. The heating medium flows into the boiler with the temperature at about 245°C, and flows out with the temperature at about 265°C. The coil-shaped tubes form the walls of the combustion chamber.

The combustion chamber of the heat medium boiler is the vertical type; the gas burner is installed on top of this vertical combustion chamber, and the flame is formed from the top towards the bottom. But the combustion gas is not emitted from the bottom. It reverses direction around the flame formed in the combustion chamber (reverse combustion), enters the counterflow heat transfer unit, and after its temperature is sufficiently reduced, it is emitted from the smoke tube. Analysis of these two heat medium boilers with gas combustion indicated no particular problems. But for the No. 300 boiler, the oxygen content of 7.8% in the flue gas is rather high, and adequate combustion control is necessary for energy savings.

5) Countermeasures

Low air ratio combustion by continuous monitoring of the flue gas O_2

6) Expenses

Refer to 6) of (1).

7) Reduction ratio

NOx: Some reduction

PM: Some increase will take place when the combustion with a low air ratio is started, but because the present emission is close to 0, a slight increase will be practically harmless.

(3) Dryers for Powdered Soap (No.1 and No.2)

1) Specification of facility

Model	Spray dryer type
Capacity	10 ton/hr (No.1) 15 ton/hr (No.2)
Draft and ventilation	Balanced draft
Construction and dimensions of furnace	Vertical cylindrical double casing 2,080ø x $5,400^H$ (No.1 and No.2)
Number of burners	1 each for hot air heater (No. 1 and No. 2)
Furnace pressure	0 mmAq (No.1 and No.2 hot air heaters) (estimated)
Other facility	Multicyclone (main equipment for recovery of products)

2) Specification of burner

Model	Partial pre-mix gas burner
Type of fuel	Natural gas
Fuel consumption	350 Nm^3/hr (No.1 hot air heater)
	365 Nm^3/hr (No.2 hot air heater)
Fuel pressure	5,000 mmAq (No.1 and No.2 hot air heaters)

3) Analytical data of flue gas

i) No. 1 hot air heater

(Stack sampling data) 14:00/Load is approx. 85% of rating

NOx (ppm)*	100	Particulate matter (g/Nm^3)	0.027
O_2 (%)	18.6	Flue gas temperature (°C)	116
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	-
CO_2 (%)	1.3		

(Emission)

	kg/hr
NOx	1.6
SO_2**	-
Particulate	1.4

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

ii) No. 2 hot air heater

(Stack sampling data) 13:00/Load is approx. 100% of rating

NOx (ppm)*	87	Particulate matter (g/Nm^3)	0.043
O_2 (%)	18.8	Flue gas temperature (°C)	82
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	-
CO_2 (%)	0.8		

(Emission)

	kg/hr
NOx	1.6
SO_2**	-
Particulate	2.7

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

There are three dryers in this soap manufacturing plant.

In the diagnostic survey, it was observed that white smoke and white solid particles were being emitted from the smoketubes of the dryers. On actual analysis of PM, the concentration values were found to be 27 and 43

mg/Nm^3, and they were much lower than expected. Since the specific gravity of the powdered soap dust is small, the concentration values obtained by the gravimetric method were very low, although it appeared much higher in the observations by eye. But since the flue gas quantity was considerablly large, the total PM quantity was 1.4 - 2.7 kg/hr and it is large when compared to other facilities.

The dryers are of a spray type in which powdered soap in the slurry state with 35% water content is sprayed from 20 nozzles at a pressure of 40 kg/cm^2g from the top part of the drying chamber. Along with this spray of slurry, hot gas of 175°C (No. 2 hot air heater) or 345°C (No. 1 hot air heater) is introduced into the drying chamber to evaporate the water content of the slurry. The slurry is in the atomized state or the state of small water droplets. Hence the surface area is large, and the drying time is short. The slurry dryed in the drying chamber space attains the powdered state, and being associated with the hot flue gas, whose temperature is reduced to about 100°C, enters the multicyclone, where the solid and gaseous particles are separated.

5) Countermeasures

i) Installation of the dust collector (bag filter)

ii) Low air ratio combustion through the regular combustion control with a potable O_2 meter

6) Expenses for installation of the dust collector (per unit)

A bag filter is installed on the exhaust gas duct of the soap powder dryer.

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	8,500
(b)	Bag filter	1 set	230,800
(c)	Blowers	1 set	36,200
(d)	On-site work supervision	1 set	7,700
(e)	On-site instruction for test operation	1 set	7,700
(f)	Travelling	1 set	12,700
(g)	Unexpected expenses (5% of the above)		15,200
	Sub-total		318,800

ii) Local portion

		(US$)
(h) Duct fabrication	1 set	57,700
(i) Foundation work	1 set	600
(j) Installation expenses	1 set	6,200
(k) Test operation and adjustment	1 set	800
(l) Vehicles for work	1 set	3,100
(m) Customs and other taxes	1 set	75,000
(n) IVA (15% excl. m)		10,260
Sub-total		153,660
Total		US$ 472,460

The freight and customs charges are not included because they differ with the packaged condition of the dust collector.

For the No.1 and No.3 dryers, the same expenses (US$ 944,920 for 2 sets) are due.

7) Reduction ratio

NOx: Some reduction

PM: 90%

(4) Summary of Control Measures

Air pollution control measures proposed for the Chemical Products Factory (A) are summarized in Table 5.2.4.

Table 5.2.4 Summary of Control Measures for Chemical Products Factory (A)

		Current Status	Control measure
Fuel type		Natural gas	Natural gas
Fuel consumption	Natural gas (10^6 m^3/yr)	77.28	77.28
Emission (ton/yr)	NOx	161.7	145 - 153
	PM	62.8	7.1
Reduction ratio (%)	NOx	-	Some reduction (5-10)
	PM	-	90
Equipment cost (1,000US$)			1,419.78 (1)
Running cost (approx) (1,000US$/yr)			
Facility depreciation (15 yr)			94.7
Interest (first 5 yrs: 8%)			113.6
Maintenance cost (5%)			71.0
Natural gas		6,440.0	6,440.0
Total (1,000US$/yr)		6,440.0	6,719.3

Note: (1) 3 bag filters for the dryers and portable O_2 meter

5.2.5 Chemical Products Factory (B)

(1) Boiler for Processing (No.1)

1) Specification of facility

Model	Flue and smoke tube type
Capacity	2.6 ton/hr
Draft and ventilation	Forced draft
Size of furnace	572 ø x $4{,}242^L$
Number of burner	1 unit (heavy oil burner)
Furnace pressure	Unknown
Ancillary facility	None

2) Specification of burner

Model	Air pressure atomization type
Type of fuel	Heavy oil
Fuel consumption	149 l/hr (estimated)
Fuel pressure	0.8 kg/cm^2g
Atomizing pressure	2.0 kg/cm^2g

3) Analytical data of flue gas

(Stack sampling data) 15:00/Load at 80% of rating

NOx (ppm)*	252	Particulate matter (g/Nm^3)	–
O_2 (%)	4.2	Flue gas temperature (°C)	215
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	–
CO_2 (%)	11.5		

(Emission)

	kg/hr
NOx	1.1
SO_2**	6.6
Particulate	0.88

NOx at rated operation is estimated to be 300 ppm (1.3 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

This boiler is used mainly for heating the reaction oven and for recovery of drain. It is the Cleaver Brooks product most widely used in Mexico.

At the time of the survey, the loading rate was low at around 50%, which can be attributed to a drop in the operation rate. According to a plant engineer, the load may increase when operation rate increases.

The burner is the air-atomization type heavy oil burner and the O_2 content of the flue gas was high at 7.6 - 7.8%. Visual observation showed rather satisfactory combustion, and thin smoke was observed from time to time from the stack. The NOx concentration was 252 ppm as converted to 5% O_2. Though combustion chamber loading was low, the sectional area load of combustion chamber was 1,430,000 kcal/hr, which is higher than that of recent low-NOx boilers since the combustion chamber is slender.

To reduce NOx, reduction of the air ratio, reduction of the N content of fuel, flue gas recirculation and use of low-NOx burner of two-stage combustion or self-recirculation type can be advised.

As regards heating efficiency, a compact design with four paths of flue gas was employed and the temperature difference between saturated steam and flue gas was about 40°C at 80% load. Installation of the air preheater is necessary if energy saving is to be enhanced further, but this is not so beneficial for this scale of boiler because measures to prevent low-temperature corrosion are necessary for current heavy oil of the high S content. The existing design is considered well-balanced for Mexico, where fuel cost is low, because recovery of investments for energy-saving above this level is expected to be very difficult.

Though the use of low-NOx burner may be considered, it is essential to cooperate with the boiler maker for installing the burner since the burner and the boiler main body are integrated.

5) Countermeasures

i) Retrofitting of the combustion equipment

(a) Combustion control
(b) Flue gas recirculation

ii) Fuel change

Change to diesel or natural gas

6) Expenses for retrofitting of equipment

Retrofitting for flue gas recirculation and fuel change to diesel or natural gas

i) Foreign portion

		(US$)
(a) Survey and design expenses	1 set	3,900
(b) Fllue gas recirculation fan	1 set	9,300
(c) Fuel pump (with accessories)	1 set	3,100
(d) Package and freight	1 set	1,700
(e) Travelling	1 set	3,900
(f) Unexpected expenses (5%)		1,100
Sub-total		23,000

ii) Local portion

		(US$)
(g) Wind box remodelling	1 set	7,700
(h) On-site work supervision	1 set	1,100
(i) Test operation and adjustment	1 set	800
(j) Customs and other taxes	1 set	3,920
(k) Warehouse, customs clearance, land freight (incl. IVA)	1 set	810
(l) IVA (15% excl. j + k)		1,440
Sub-total		15,770
Total		US$ 38,770

7) Reduction ratio

NOx : 25%

SO_2 : 82%

PM : 20%

(2) Oil Heating Furnace

1) Specification of facility

Model	Once-through type
Draft and ventilation	Natural draft
Size of furnace	400^W x $1,710^D$ x 230^H
Number of burner	1 unit (oil burner)

Furnace pressure | Atmospheric pressure
Ancillary facility | None

2) Specification of burner

Model	Oil pressure atomization type
Type of fuel	Diesel
Fuel consumption	8.3 l/hr
Fuel pressure	Unknown

3) Analytical data of flue gas

(Stack sampling data) 13:00/Load at 70% of rating

NOx (ppm)*	34	Particulate matter (g/Nm^3)	0.033
O_2 (%)	10.3	Flue gas temperature (°C)	370
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	-
CO_2 (%)	7.6		

(Emission)

	kg/hr
NOx	0.01
SO_2**	0.13
Particulate	0.0036

NOx at rated operation is estimated to be 48 ppm (0.02 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

This is an one-through, oil heating furnace used for tube heating in a brick furnace. Fuel injection is made into the naturally-drafted combustion chamber by a pressure-atomization-type burner. Atomization was poor and the injected fuel was impinging on the furnace floor. Unsatisfactory combustion appeared contrarily to help suppression of NOx generation. Thin fumes were observed from the stack. Air supply was excessive. Improvement in furnace efficiency is necessary. Retrofitting of the furnace is recommended.

5) Countermeasures

Although retrofitting of the furnace is desirable, it is not urgent, because diesel is used as the fuel and the combustion rate is low at 8.3 l/hr. Improvement of burner nozzles is desirable.

6) Expenses

Burner nozzle: US$ 2,000

excl. customs duty, clearance, domestic freight, and installation costs

(3) Summary of Control Measures

Table 5.2.5 summarizes control mesures for the Chemical Products Factory (B).

Table 5.2.5 Summary of Control Measure for Chemical Products Factory (B)
(2.6 ton/hr flue and smoke tube type boiler)

		Current Status	Control measure
Fuel type		Heavy oil 89.4%	Diesel 100%
		Diesel 10.6%	
Fuel consumption	Heavy oil (10^3 m^3/yr)	0.6768	-
	Diesel (10^3 m^3/yr)	0.0804	0.7572
Emission (ton/yr)	NOx	6.4	4.8
	SO_2	42.2	7.6
	PM	5.1	4.1
Reduction ratio (%)	NOx		25%
	SO_2		82%
	PM		20%
Equipment cost (1,000US$)			40.77 (1)
Running cost (approx) (1,000US$/yr)			
Facility depreciation (15 yr)			2.7
Interest (first 5 yrs: 8%)			3.3
Maintenance cost (5%)			2.0
Heavy oil		52.5	-
Diesel		16.5	155.8
Total (1,000US$/yr)		69.0	163.8

Note: (1) - Retrofitting of boiler No.1 for flue gas recirculation and fuel change to diesel
- Change of the burner nozzle of the oil heating furnace

5.2.6 Chemical Products Factory (C)

(1) Boiler for Processing (No.1)

1) Specification of facility

Model	Flue and smoke tube type
Capacity	2.4 ton/hr
Draft and ventilation	Forced draft
Size of furnace	610ø x 3,454L
Number of burners	One unit (natural gas burner)
Ancillary facility	None

2) Specification of burner

Model	Cone mix
Type of fuel	Natural gas
Fuel consumption	168 m^3/hr
Fuel pressure	3.2/0.027 kg/cm^2g

3) Analytical data of flue gas

(Stack sampling data) 14:45/Load at 35 ~ 40% of rating

NOx (ppm)*	66	Particulate matter(g/Nm^3)	0.0075
O_2 (%)	10.8	Flue gas temperature (°C)	164
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	-
CO_2 (%)	5.3		

(Emission)

	kg/hr
NOx	0.04
SO_2**	-
Particulate	0.0037

NOx at rated operation is estimated to be 155 ppm (0.09 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

This is a resin paint plant. Steam from the boiler is used to heat the resin and the drain is recovered. This boiler and a 1.6 ton/hr boiler installed in parallel are under the automatic control, therefore, the combustion volume fluctuated widely. Manual setting of the combustion volume is said to be impossible.

Operation is made 24 hours a day from 6:00 on Monday to 22:00 on Friday, that is, 116 hours a week. A contract for maintenance is made with a maintenance company and analyses of O_2, H_2, CO_2, and CO are made by the gas chromatography. But the standard for adjustment was unknown.

This boiler was made by Cleaver Brooks and it employs a cone mix type natural gas burner. The loads of both the combustion chamber and the chamber sectional area were high. This is not favorable for control of NOx. But the measured NOx concentration was low. This data, however, were obtained for a small load with an extremely high air ratio of 7.5 - 11.8%. The fuel control valve moved up and down incessantly due to capacity control. Since the burner of the Cleaver Brooks made boiler has a mechanism by which the air ratio can be freely adjusted for each combustion amount by using a cam, a plant of this kind should have at least a O_2 meter to control the O_2 content daily at an appropriate level according to the combustion volume.

NOx reduction measures are not necessary because the total NOx generation rate and NOx concentration are low.

On the other hand, at this factory, a large amount of solvents (300 l/mon or equivalent to approx. 2% of the products), is leaking from the paint manufacturing process and emitted into the atmosphere without any preventive measure. The factory is currently planning two-step control measures: step 1 for installation of a ventilation duct for improvement of working environment, and step 2 for adopting a leak prevention system for the manufacturing process. Because of the importance of the control of HC, which is one of major substances to cause photochemical smog, early materialization of the plan is desirable.

(2) Boiler for Processing (No.2)

1) Specification of facility

Model	Flue and smoke tube
Capacity	1.7 ton/hr
Draft and ventilation	Forced draft
Size of furnace	508^{ϕ} x $2{,}000^{L}$
Number of burner	One unit (natural gas burner)
Furnace pressure	Unknown
Ancillary facility	None

2) Specification of burner

Model	Cone mix
Type of fuel	Natural gas
Fuel consumption	112 m^3/hr
Fuel pressure	3.2 kg/cm^2g (primary)

3) Analytical data of flue gas

(Stack sampling data) 15:45/Load at 40% of rating

NOx (ppm)*	51	Particulate matter (g/Nm^3)	<0.0009
O_2 (%)	7.1	Flue gas temperature (°C)	154
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	-
CO_2 (%)	7.2		

(Emission)

	kg/hr
NOx	0.02
SO_2**	-
Particulate	<0.0002

NOx at rated operation is estimated to be 120 ppm (0.05 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

Same as for No.1 boiler.

(3) Countermeasures, Expenses and Reduction Effects

1) Countermeasures

i) Countermeasures for boiler

Periodical combustion control with a portable O_2 meter for operation at optimum air ratio.

ii) Prevention of solvent leaking from the manufacturing process and treatment of evaporated solvent

(a) To reduce the leakage of solvent from the manufacturing process to a half, the manufacturing equipment should be cooled down to 5 to 7°C. This method is effective in improving solvent yield and in improving product quality.

(b) To treat the evaporated solvent, a solvent treatment furnace should be installed. The indoor air containing the solvent should be ducted to a gas burner for direct burning. Although the installation of a waste heat boiler to the treatment furnace and the use of catalytic oxidation are conceivable, they are not recommended in place of the direct burning on account of high installation cost and catalyst and other operation costs.

2) Expenses

i) For boiler operation with appropriate air ratio

Portable O_2 meter US$ 2,400

ii) Expenses of the solvent leak prevention measure

(a) Currently, the factory is planning to cool down the manufacturing facility

(b) Installation expenses of the direct burning furnace (existing ventilation duct will be utilized)

Natural gas burner, duct, incinerator, etc. US$ 113,200

(excluding customs duty, customs clearance expenses, domestic freight, installation costs, etc.)

3) Expected reduction effect

i) By optimum air ratio combustion:

Fuel :	2% (3%)
NOx :	17% (23%)
PM :	a slight increase, but almost harmless

Values in ( ) are for the 1.7 ton/hr boiler.

ii) Solvent leak prevention:

(a) By cooling the manufacturing equipment

HC: approx. 50%

(b) By direct burning:

HC: approx. 90% for the HC containing air

4) Summary of Control measures

Table 5.2.6 summarizes the control measures for the Chemical Product Factory (C).

Table 5.2.6 Summary of Control Measure for Chemical Products Factory (C)

		Current Status	Control measure
Fuel type		Natural gas	Natural gas
Fuel consumption	Natural gas (10^6 m^3/yr)	0.108	0.108
Emission (ton/yr)	NOx	0.032	0.032
	PM	< 0.002	< 0.002
Reduction ratio (%)	NOx		0
	PM		0
	HC		90 (1)
Equipment cost (1,000US$)			115.60 (2)
Running cost (approx) (1,000US$/yr)			
Facility depreciation (15 yrs)			7.7
Interest (first 5 yrs: 8%)			9.2
Maintenance cost (5%)			5.8
Natural gas		9.0	9.0
Total (1,000US$/yr)		9.0	31.7

Note: (1) Reduction ratio for the HC gas induced into the duct
(2) - Potable O_2 meter
- Natural gas burner, duct, and incinerator for prevention of HC leakage.

5.2.7 Chemical Products Factory (D)

1) Name of facility surveyed — Boiler for Processing (No.4)

2) Specification of facility

Model	Water tube boiler
Capacity	7.7 ton/hr
Draft and ventilation	Forced draft
Dimensions of furnace	$1{,}664^{W} \times 4{,}200^{D} \times 2{,}200^{H}$
Number of burner	1 burner
Furnace pressure	+10 mmAq
Ancillary facility	None

3) Specification of burner

Model	Ring type gas burner
Type of fuel	Natural gas
Fuel consumption	770 Nm^3/hr
Fuel pressure	850 mmAq

4) Analytical data of flue gas

(Stack sampling data) 13:30/Load is approx. 70% of rating

NOx (ppm)*	42	Particulate matter (g/Nm^3)	<0.0002
O_2 (%)	1.8	Flue gas temperature (°C)	280
CO (%)	0.15	Combustion chamber outlet O_2 (%)	–
CO_2 (%)	9.8		

(Emission)

	kg/hr
NOx	0.50
SO_2**	–
Particulate	<0.001

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

5) Observation

This factory manufactures sodium and chlorine by electrolysis of common salt. Sodium-mercury amalgam is produced during the process and there is an outflow of as much as 150 g of mercury per month. Care must be taken.

There are two boilers operating in this factory with the same capacity of 7.7 ton/hr. These are alternately used for heating salt water. The boilers are automated and the load variation is large, so measurements were done in the diagnostic survey by manual operation. However, since the maintenance was inadequate, the air ratio was incorrect, with 1,500 ppm of CO generated at an oxygen level of 1.9%. But when the oxygen is brought to a level of 2.3 to 3.0%, the CO was reduced to less than 0.05%. Therefore it is desirable that this furnace be operated at an oxygen level of around 2.5%.

6) Countermeasures

Combustion control by regularly using a potable O_2 meter to achieve the operation with the appropriate air ratio.

7) Expenses

Portable O_2 meter US$2,400
(excl. customs duty, customs clearance expenses, and domestic freight)

8) Expected reduction effect

CO: Present CO concentration of 0.15% at 1.9% O_2 can be reduced to 0.05% or less by operation with about 2.5% O_2

NOx: Same level as present

PM: Same level as present; nearly zero

5.2.8 Chemical Products Factory (E)

1) Name of facility surveyed — Boiler for processing (No.1)

2) Specification of facility

Model	Water-tube type
Capacity	7.8 ton/hr
Draft and ventilation	Forced draft
Size of furnace	$2{,}600^W \times 3{,}000^D \times 2{,}850^H$
Number of burners	2 units
Furnace pressure	-7 ~ -8 mmH_2O
Ancillary facility	None

3) Specification of burner

Model	Steam atomization type
Type of fuel	Heavy oil
Fuel consumption	567 l/hr (estimated)
Fuel pressure	11.5 kg/cm^2g
Atomizing pressure	11.5 kg/cm^2g (steam)

4) Analytical data of flue gas

(Stack sampling data) 13:00/Load at 80% of rating

NOx (ppm)*	168	Particulate matter (g/Nm^3)	0.051
O_2 (%)	7.0	Flue gas temperature (°C)	295
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	–
CO_2 (%)	9.2		

(Emission)

	kg/hr
NOx	1.7
SO_2**	10
Particulate	0.29

NOx at rated operation is estimated to be 225 ppm (2.3 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

5) Observation

This boiler is used to generate process steam at this soap manufacturing and cooking oil refining plant and no drain is returned. The boiler is operated 24 hours a day, except for the period from 6:00 to 22:00 on Sunday, with the total operation hours of 152 per week.

This water-tube boiler is a furnace type with an induced fan; it was installed in 1951. Control of combustion and water supply are made manually by boiler operators working three shifts a day.

Loading, though varying with the status of the manufacturing process at each plant, is made under a certain established pattern for each day.

The burner is the steam-atomization type, but its atomization performance was not so satisfactory and the air ratio was more or less high, possibly due to manual operation. The NOx concentration was 168 ppm as converted to 5% O_2, which is not so high for a burner without NOx control. Though NOx reduction may be possible by decreasing the air ratio, there is still a concern about the effect of particulate matter. Since the use of desulfurized heavy oil alone is not the adequate measure because of unsatisfactory atomization by the existing burner, the use of low-NOx burners is also considered necessary.

6) Countermeasures

i) Retrofitting of combustion equipment (boiler)

(a) Combustion with a low air ratio through constant monitoring of the flue gas O_2

(b) Installation of the low NOx burner

ii) Fuel change

(a) Mixed combustion with 50% heavy oil and 50% diesel or natural gas up to the supply start of desulfurized heavy oil

(b) When supply of desulfurized heavy oil is started, it should be used exclusively (100%)

(c) Emulsified combustion of desulfurized heavy oil should be taken into consideration after thorough demonstration tests.

7) Expenses

Retrofitting of the boiler for a low air ratio combustion, installation of the low NOx burner and for mixed burning of heavy oil and diesel

i) Foreign portion

		(US$)
(a) Survey and design	1 set	3,900
(b) Low NOx burner (500 l/hr)	2 units	61,600
(c) Combustion control system and electric instrumentation	1 set	23,100
(d) Package and freight	1 set	10,800
(e) Travelling	1 set	3,900
(f) Unexpected expenses (5% of the above)		5,200
Sub-total		108,500

ii) Local portion

		(US$)
(g) Burner removal and installation work	1 set	1,600
(h) Local installation on-site supervision	1 set	3,100
(i) On-site instruction for test operation	1 set	800
(j) Customs and other taxes	1 set	27,950
(k) Warehouse, customs clearance, and land freight (incl. IVA)	1 set	2,000
(l) IVA (15% excl. j + k)		830
Sub-total		36,280
Total		US$ 144,780

8) Summary of Control Measures

Table 5.2.8 summarizes the control measures for the Chemical Products Factory (E).

Table 5.2.8 Summary of Control Measures for Chemical Products Factory (E)

		Current status	Countermeasure		
		Heavy poil	A	B	C
Fuel type (Boiler No.1)		Heavy oil	Heavy oil 50% Diesel 50%	Desulfurized heavy oil	Desulfurized heavy oil
Combustion method		-	-	-	Emulsified combustion
Fuel consumption (Plant total)	Heavy oil (10^3 m^3/yr)	1.644	0.822	1.644	1.644
	Diesel (10^3 m^3/yr)	1.383	2.205	1.383	1.383
Emission (ton/yr)	NOx	18.2	10.2	13.1	10.2
	SO_2	126.3	71.4	40.1	40.1
	PM	3.4	2.9	2.9	2.3
Reduction ratio (%)	NOx		44	28	44
	SO_2		43	68	68
	PM		14	14	32
Equipment cost			144.78	144.78	144.78
Running cost (approx.)(1,000US$)					
Facility depreciation (15-yrs)			9.7	9.7	9.7
Interest (first 5 yrs: 8%)			11.6	11.6	11.6
Maintenance cost (5%)			7.2	7.2	7.2
Heavy oil		127.5	63.7	-	-
Diesel		284.6	453.7	284.6	284.6
Desulfurized heavy oil		-	-	178.9	-
Desulfurized heavy oil emulsion		-	-	-	218.1
Total (1,000US$/yr)		412.1	545.9	492.0	531.2

Alternative B: Applicable after the start of supplying desulfurized heavy oil
Alternative C: Emulsified combustion of the desulfurized heavy oil should be considered after thorough demonstration tests.

5.2.9 Petrochemical Products Factory (A)

(1) Power Generation Boiler (No.3)

1) Specification of facility

Model	Water tube boiler
Capacity	28 ton/hr
Draft and ventilation	Forced draft
Dimensions of furnace	$3{,}197^W \times 5{,}543^D \times 5{,}500^H$
Number and layout of burners	3 (Two at the bottom and one at the top)
Furnace pressure	+19 mmAq
Ancillary facility	Recuperator (30 → 220°C)

2) Specification of burner

Model	Gas and oil mixing type burner, Gas: Lance type Oil: Y - jet type
Type of fuel	Heavy oil (only heavy oil is used at present)
Fuel consumption	885 l/hr
Fuel pressure	4 kg/cm^2g
Atomize pressure	8.5 kg/cm^2g (steam)

3) Analytical data of flue gas

(Stack sampling data) 13:30/Load is approx. 86% of rating

NOx (ppm)*	387	Particulate matter (g/Nm^3)	0.078
O_2 (%)	8.8	Flue gas temperature (°C)	210
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	3.3
CO_2 (%)	9.6		

(Emission)

	kg/hr
NOx	15
SO_2**	120
Particulate	2.0

NOx at rated operation is estimated to be 390 ppm (18 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

This 28 ton/hr boiler is used for power generation. The NOx concentration of this boiler is high at 387 ppm (corrected to O_2 = 5%), but the PM concentration is quite low considering heavy oil combustion. The width of this boiler with 3.2 m is small compared to its depth of 5.54 m. The three burners are grouped together on the side wall (top stage 1 burner, bottom stage 2 burners), and are arranged for firing towards the opposite wall. Since the short flames with high speed combustion are required because of the short distance between the burners and the wall, and a highly loaded combustion region is formed due to the grouped flames of the group of burners, the NOx concentration in this region becomes high. Furthermore, this high concentration region bends and flows towards the outlet, therefore, the detention time for NOx generation is prolonged. This is considered to be the cause for the high NOx concentration.

According to the flue gas analysis data, the oxygen concentration at the combustion chamber outlet is 3.3%, and that at the recuperator outlet is 7.7%. From these figures it is apparent that there is a leak in the recuperator. Immediate repair is needed.

5) Countermeasures

i) Retrofitting of the boiler

(a) Repair for eliminating the air preheater leakage

(b) Low air ratio combustion by constant monitoring of the flue gas O_2

(c) Off-stoichiometric combustion and flue gas recirculation.

ii) Fuel change

(a) Mixed combustion with 50% heavy oil and 50% natural gas up to the supply start of desulfurized heavy oil

(b) When supply of desulfurized heavy oil supply is started, it should be used exclusively (100%)

(c) Emulsified combustion of desulfurized heavy oil should be considered after thorough demonstration tests.

iii) Installation of the NOx and O_2 telemeters for constant flue gas monitoring

6) Expenses for boiler retrofitting

Retrofitting for off-stoichiometric combustion, flue gas recirculation and low air ratio combustion, as well as air preheater repair.

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	15,400
(b)	Flue gas recirculation fan	1 set	16,200
(c)	Combustion control system and electric instrumentation	1 set	46,200
(d)	Local work on-site supervision	1 set	7,700
(e)	On-site instruction for test operation	1 set	5,400
(f)	Package and freight	1 set	5,400
(g)	Travelling	1 set	10,400
(h)	Unexpected expenses (5% of the above)		5,300
	Sub-total		112,000

ii) Local portion

			(US$)
(i)	Duct fabrication (incl. heat insulation)	1 set	23,000
(j)	Duct and fan installation and electric instrumentation work	1 set	11,500
(k)	On-site instruction for test operation	1 set	2,300
(l)	Customs and other taxes	1 set	18,000
(m)	Warehouse, customs clearance, and land freight (incl. IVA)	1 set	1,300
(n)	IVA (15% excl. l + m)		5,520
	Sub-total		61,620
	Total		US$ 173,620

(2) Power Generation Boiler (No.4)

1) Specification of facility

Model	Water tube boiler
Capacity	41 ton/hr
Draft and ventilation	Forced draft
Dimensions of furnace	$4,619^{W} \times 5,081^{D} \times 5,600^{H}$
Number of burners	4 units
Furnace pressure	+80 mmAq
Ancillary facility	Recuperator (30 → 220°C)

2) Specification of burner

Model	Gas and oil mixing type burner, Gas: Lance type, Oil: Y - jet type
Type of fuel	Natural gas (only natural gas is used at present)
Fuel consumption	1,140 Nm^3/hr/burner
Fuel pressure	1 kg/cm^2g

3) Analytical data of flue gas

(Stack sampling data) 14:30/Load is approx. 78% of rating

NOx (ppm)*	194	Particulate matter (g/Nm^3)	<0.0001
O_2 (%)	7.4	Flue gas temperature (°C)	270
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	5.5
CO_2 (%)	6.7		

(Emission)

	kg/hr
NOx	12
SO_2**	-
Particulate	<0.0035

NOx at rated operation is estimated to be 195 ppm (15 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

The capacity of the boiler at 41 ton/hr is rather small considering the use for power generation, but as a natural gas combustion boiler, the amount of NOx generated is considerably large. The cause for the high NOx concentration is considered to be the same as in the No. 3 boiler.

The oxygen concentration in the exhaust gas at the combustion chamber outlet was 5.5%, but that at the recuperator outlet was high at 7.4%. Although it is lower than the No. 3 heavy oil boiler, air leakage in the recuperator may be occurring. Proper maintenance is required.

Since the air ratio is too high for a gas combustion boiler, low air ratio operation is necessary.

5) Countermeasures

i) Retrofitting of combustion facility

(a) Repair for eliminating the air preheater leakage

(b) Low air ratio combustion through constant monitoring of the flue gas O_2

(c) Installation of the fan for flue gas recircuation, and installation of low NOx burners

ii) Continuous monitoring of the flue gas by installing the NOx, SO_2, O_2 telemeters

6) Expenses for boiler retrofitting

Retrofitting for flue gas recirculation, low NOx burner installation, low air ratio combustion, and repair of air preheater.

i) Foreign portion

		(US$)
(a) Survey and design	1 set	15,400
(b) Flue gas recirculation fan	1 set	17,000
(c) Low NOx burner	1 set	206,200
(d) Combustion control system and electric instrumentation	1 set	54,000
(e) Local work on-site supervision	1 set	23,100
(f) On-site instruction for test operation	1 set	7,700
(g) Package and freight	1 set	10,700
(h) Travelling	1 set	10,400
(i) Unexpected expenses (5% of the above)		17,200
Sub-total		361,700

ii) Local portion

		(US$)
(j) Burner and duct removal work	1 set	1,600
(k) Duct fabrication (incl. heat insulation)	1 set	30,800
(l) Burner installation	1 set	2,000
(m) Installation of duct, fan and electric instrumentation	1 set	16,900
(n) On-site instruction for test operation	1 set	2,300
(o) Customs and other taxes	1 set	82,700
(p) Warehouse, customs clearance, and domestic freight (incl. IVA)	1 set	1,020
(q) Duct, etc. freight and crane rental	1 set	2,000
(r) IVA (15% excl. o + p)		8,340
Sub-total		147,660
Total		US$ 509,360

(3) Expenses for Installation of Telemeteric Monitoring System for Flue Gas

Installation of NOx and O_2 meters for the boilers No.1 and No.3 and SO_2, NOx and O_2 meters for boiler No.4 for the continuous monitoring of flue gas by the telemetric system.

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	7,700
(b)	NOx, SO_2, O_2 instrumentation	3 sets	128,000
(c)	Auxiliary units	3 sets	60,000
(d)	Data logger	1 set	17,900
(e)	Installation work on-site supervision	1 set	8,500
(f)	On-site instruction for test operation	1 set	4,700
(g)	Package and freight	1 set	38,000
(h)	Travelling	1 set	12,200
(i)	Unexpected expenses (5% of the above)		13,800
	Sub-total		291,690

ii) Local portion

			(US$)
(j)	Materials	1 set	6,300
(k)	Survey assistant	1 set	1,600
(l)	Installation works	1 set	6,500
(m)	Test operation and adjustment	1 set	1,900
(n)	Vehicle rental	1 set	3,300
(o)	Customs and other taxes	1 set	56,210
(p)	Warehouse, customs clearance, and land freight (incl. IVA)	1 set	4,530
(q)	IVA (15% excl. o + p)		2,940
	Sub-total		83,280
	Total		US$ 374,970

(Telephone installation work and central reception system are not included.)

(4) Summary of Control Measures

Table 5.2.9 summarizes the control measures for the Petrochemical Products Factory (A).

Table 5.2.9 Summary of Control Measures for Petrochemical Products Factory (A)

		Current status	Countermeasure		
		Heavy oil	A	B	C
Fuel type (Note)		Heavy oil	Heavy oil 50% Natuiral gas 50%	Desulfurized heavy oil	Desulfurized heavy oil
Combustion method		-	-	-	Emulsified combustion
Fuel consumption (Plant total)	Heavy oil (10^3 m^3/yr)	18.0	9.0	18.0	18.0
	Natural gas (10^6 m^3/yr)	25.9	35.9	25.9	25.9
Emission (ton/yr)	NOx	248.7	154.7	179.1	139.3
	SO_2	1,080	540	288	288
	PM	17.5	8.75	14.0	10.5
Reduction ratio (%)	NOx	-	38	15	43
	SO_2	-	50	73	73
	PM	-	50	20	40
Equipment cost (1,000US$)	Equipment expenses		682.98	682.98	682.98
	NOx, SO_2 telemeter		374.97	374.97	374.97
Running cost (approx.)(1,000US$)					
Facility depreciation (15-yrs)			70.5	70.5	70.5
Interest (first 5 yrs: 8%)			84.6	84.6	84.6
Maintenance cost (5%)			52.9	52.9	52.9
Heavy oil		1,395.9	698.0	-	-
Natural gas		2,158.3	2,991.6	2,158.3	2,158.3
Desulfurized heavy oil		-	-	1,959.2	-
Desulfurized heavy oil emulsion		-	-	-	2,387.7
Total (1,000US$/yr))		3,554.2	3,897.6	4,325.5	4,754.0

Alternative B: Applicable after the start of supplying desulfurized heavy oil
Alternative C: Emulsified combustion of the desulfurized heavy oil should be considered after thorough demonstration tests.
Note: Types of fuel for the boiler No.3. The boilers No.1, No.2 and No.4 currently use natural gas as well as in the future.

5.2.10 Petrochemical Products Factory (B)

(1) Power Generation Boiler (No.2)

1) Specification of facility

Model	Water tube boiler
Capacity	40 ton/hr
Draft and ventilation	Forced draft
Dimensions of furnace	$2{,}196^W \times 7{,}381^D \times 4{,}674^H$
Number of burner	1 burner
Furnace pressure	+200 mmAq
Ancillary facility	Air preheater (30 → 170°C)

2) Specification of burner

Model	Y-jet type
Type of fuel	Heavy oil
Fuel consumption	3,400 l/hr
Fuel pressure	4 kg/cm^2g
Atomizing pressure	6 kg/cm^2g (steam)

3) Analytical data of flue gas

(Stack sampling data) 12:30/Load is approx. 65% of rating

NOx (ppm)*	250	Particulate matter (g/Nm^3)	0.037
O_2 (%)	5.2	Flue gas temperature (°C)	217
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	2.9
CO_2 (%)	11.0		

(Emission)

	kg/hr
NOx	19
SO_2**	130
Particulate	1.4

NOx at rated operation is estimated to be 275 ppm (32 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

This plant manufactures chemical fibers such as nylon and polyester.

The boiler No.2 is used for power generation. The drum pressure is 42 kg/cm^2g and steam temperature is 385°C. The power generation rate at the time of the diagnostic survey was 3,400 kw/hr.

The NOx concentration of 250 ppm is an average value for heavy oil combustion boilers. The PM concentration of 37 mg/Nm^3 is relatively low for heavy oil combustion boilers. The flue gas oxygen concentration of 2.9% at the combustion chamber outlet is an appropriate value for operation, and combustion control is also properly made. However, the oxygen concentration in the flue gas at the smoke tube is as high as 5.2%. Therefore, there is doubtlessly air leakage in the recuperator probably due to low temperature corrosion.

5) Countermeasures

i) Retrofitting of combustion equipment

(a) Air preheater repair

(b) Low air ratio combustion by regular monitoring of the flue gas O_2

(c) Flue gas recirculation by installing the flue gas blower and low NOx burner installation

ii) Fuel change

(a) Mixed combustion with 50% heavy oil and 50% diesel or natural gas up to the supply start of desulfurized heavy oil

(b) When supply of desulfurized heavy oil is started, it should be used exclusively (100%)

(c) Emulsified combustion of desulfurized heavy oil should be taken into consideration after thorough demonstration tests.

iii) Regular monitoring of the flue gas by installing the NOx and SO_2 telemeters

6) Expenses for boiler retrofitting

Low NOx burner, flue gas recirculation, low air ratio combustion and air preheater repair.

i) Foreign portion

		(US$)
(a) Survey and design	1 set	19,300
(b) Low Nox burner	1 set	107,700
(c) Flue gas recirculation fan	1 set	32,300

(d)	Combustion control system and instrumentation	1 set	46,200
(e)	On-site work supervision	1 set	15,400
(f)	On-site instruction for test operation	1 set	7,700
(g)	Package and freight	1 set	16,200
(h)	Travelling	1 set	12,100
(i)	Unexpected expenses (5% of the above)		12,800
	Sub-total		269,700

ii) Local portion

			(US$)
(j)	Burner removal	1 set	1,600
(k)	Duct fabrication	1 set	27,000
(l)	Burner, duct, fan installation	1 set	5,400
(m)	Electric instrumentation installation	1 set	15,400
(n)	Test operation and adjustment	1 set	2,300
(o)	Customs and other taxes	1 set	58,900
(p)	Warehouse, customs clearance, and land freight (incl. IVA)	1 set	6,000
(q)	Duct, etc. freightage and crane rental	1 set	2,000
(r)	IVA (15% excl. o + p)		8,000
	Sub-total		*126,600*
	Total		US$ 396,300

Note: For other boilers which are of the same type as the No.2 boiler, the same retrofitting expenses (US$ 396,300) is applicable.

(2) Boiler for Processing (No.3)

1) Specification of facility

Model	Water tube boiler
Capacity	13 ton/hr
Draft and ventilation	Forced draft
Dimensions of furnace	$1{,}767^W \times 4{,}627^D \times 2{,}400^H$
Number of burner	1 burner
Furnace pressure	+20 mmAq
Ancillary facility	None

2) Specification of burner

Model	Y-jet type
Type of fuel	Heavy oil
Fuel consumption	1,200 l/hr
Fuel pressure	4 kg/cm^2g
Atomizing pressure	6 kg/cm^2g (steam)

3) Analytical data of flue gas

(Stack sampling data) 12:30/Load is approx. 50% of rating

NOx (ppm)*	336	Particulate meter (g/Nm^3)	0.23
O_2 (%)	5.8	Flue gas temperature (°C)	253
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	–
CO_2 (%)	12.0		

(Emission)

	kg/hr
NOx	4.0
SO_2**	34
Particulate	1.4

NOx at rated operation is estimated to be 370 ppm (8.8 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

The boiler No.3 is used for heating, humidity conditioning, and drying in the production processes. The load variation of this boiler is very high, and its operation was changed over to manual mode at the time of the diagnostic survey.

The NOx concentration of 336 ppm is quite high. Although the PM concentration was 230 mg/Nm^3, this value is not so high for the heavy oil combustion. The oxygen concentration of the flue gas at the combustion chamber outlet at 5.8% lies in the appropriate range. But this boiler has a long and slender combustion chamber in comparison to cross sectional area. Consequently, when reduction of NOx generation is attempted by slow combustion with a long flame, the flame will run along the side wall of the combustion chamber, and carbon deposits will be formed on the side wall. To avoid these, high speed combustion is employed that may have caused an abnormally high NOx concentration.

5) Countermeasures

i) Retrofitting of combustion equipment

(a) Low air ratio combustion by regular monitoring of the flue gas O_2

(b) Flue gas recirculation by installing the flue gas blower and low NOx burner installation

(c) Two-stage combustion

ii) Fuel change

(a) Mixed combustion with 50% heavy oil and 50% diesel or natural gas up to the supply start of desulfurized heavy oil

(b) When supply of desulfurized heavy oil is started, it should be used exclusively (100%)

(c) Emulsified combustion of desulfurized heavy oil should be taken into consideration after thorough demonstration tests.

iii) Regular monitoring of the flue gas by installing the NOx, SO_2 and O_2 telemeters

6) Expenses for boiler retrofitting

Rebuilding of burners, etc. for 2-stage combustion, flue gas recirculation and low air ratio combustion

i) Foreign portion

		(US$)
(a) Survey and design	1 set	9,300
(b) Burner	1 set	77,000
(c) Flue gas recirculation fan	1 set	12,300
(d) Combustion control instrumentation and electric system	1 set	27,000
(e) On-site work supervision	1 set	5,400
(f) On-site instruction for test operation	1 set	5,400
(g) Package and freight	1 set	14,000
(h) Travelling	1 set	11,200
(i) Unexpected expenses (5% of the above)		8,080
Sub-total		169,680

ii) Local portion

			(US$)
(j)	Burner removal and installation	1 set	1,600
(k)	Duct fabrication	1 set	17,700
(l)	Burner, duct, fan installation	1 set	2,000
(m)	Electric instrumentation installation	1 set	13,900
(n)	Test operation and adjustment	1 set	600
(o)	Customs and other taxes	1 set	36,840
(p)	Warehouse, customs clearance, and land freight (incl. IVA)	1 set	2,400
(q)	IVA (15% excl. o + p)		5,370
	Sub-total		80,410
	Total		US$ 250,090

(3) Regular Monitoring for the Flue Gas by NOx, SO_2 and O_2 Telemeters

Expenses for telemeter instrumentation system on the stacks of No.2 and No.3 boilers.

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	6,200
(b)	NOx, SO_2, O_2 instrumentation	2 sets	118,600
(c)	Auxiliary units	2 sets	41,100
(d)	Data logger	1 set	17,900
(e)	Installation work on-site supervision	1 set	8,500
(f)	On-site instruction for test operation	1 set	4,700
(g)	Package and freight	1 set	25,900
(h)	Travelling	1 set	11,900
(i)	Unexpected expenses (5% of the above)		11,740
	Sub-total		246,540

ii) Local portion

			(US$)
(j)	Materials	1 set	4,200
(k)	Survey assistant	1 set	1,300
(l)	Installation expenses	1 set	4,400
(m)	Test operation and adjustment	1 set	1,400

(n)	Vehicles	1 set	2,200
(o)	Customs and other taxes	1 set	41,690
(p)	Warehouse, customs clearance, and land freight (incl. IVA)	1 set	3,250
(q)	IVA (15% excl. o + p)		2,030
	Sub-total		60,470
	Total		US$ 307,010

(Telephone installation work and central reception system are not included.)

Note: Boilers No.1 and No.2 are operated alternately, and accordingly, the monitoring system is also to be operated alternatively.

(4) *Summary of Control Measures*

Table 5.2.10 summarizes the control measures for the Petrochemical Products Factory (B).

Table 5.2.10 Summary of Control Measures for Petrochemical Products Factory (B)

		Current status	Countermeasure		
			A	B	C
Fuel type		Heavy oil	Heavy oil 50% Diesel 50%	Desulfurized heavy oil 100%	Desulfurized heavy oil 100%
Combustion method		-	-	-	Emulsified combustion
Fuel consumption	Heavy oil (10^3 m^3/yr)	30.72	15.36	30.72	30.72
	Diesel (10^3 m^3/yr)	-	15.36	-	-
Emission (ton/yr)	NOx	261.8	128.3	164.9	128.3
	SO_2	1,843.2	1,075.2	491.5	491.5
	PM	26.0	20.8	20.8	15.6
Reduction ratio (%)	NOx		51	37	51
	SO_2		41	73	73
	PM		20	20	40
Equipment cost (1,000US$)	Equipment expenses		1,042.69	1,042.69	1,042.69
	NOx, SO_2 telemeter		307.01	307.01	307.01
Running cost (approx.)(1,000US$)					
Facility depreciation (15-yrs)			90.0	90.0	90.0
Interest (first 5 yrs: 8%)			108.0	108.0	108.0
Maintenance cost (5%)			67.5	67.5	67.5
Heavy oil		2,382.4	1,191.2	-	-
Diesel		-	3,160.8	-	-
Desulfurized heavy oil		-	-	3,343.7	-
Desulfurized heavy oil emulsion		-	-	-	4,075.1
Total (1,000US$/yr		2,382.4	4,617.5	3,609.2	4,340.6

Alternative B: Applicable after the start of supplying desulfurized heavy oil.
Alternative C: The emulsifued combustion of desulfurized heavy oil should be considered after thorough demonstration tests.

5.2.11 Petrochemical Products Factory (C)

1) Name of facility surveyed — Boiler for processing (No.1)

2) Specification of facility

Model	Flue and smoke tube type
Capacity	2.4 ton/hr
Draft and ventilation	Forced draft
Size of furnace	$564^{\phi} \times 3{,}500^{L}$
Number of burner	One unit
Furnace pressure	Unknown
Ancillary facility	None

3) Specification of burner

Model	Air pressure atomization type
Type of fuel	Heavy oil
Fuel consumption	158 l/hr (Rating)
Fuel pressure	1.6/0.6 kg/cm^2

4) Analytical data of flue gas

(Stack sampling data) 13:00/Load at 85% of rating

NOx (ppm)*	346	Particulate matter (g/Nm^3)	0.19
O_2 (%)	8.3	Flue gas temperature (°C)	250
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	–
CO_2 (%)	8.0		

(Emission)

	kg/hr
NOx	1.1
SO_2**	7.4
Particulate	0.23

NOx at rated operation is estimated to be 400 ppm (1.3 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

5) Observation

This is a flue and smoke tube boiler made by Cleaver Brooks, which generates steam to heat a reaction oven which produces various resins. It is operated continuously from 6:00 on Monday to 22:00 on Saturday, 136 hours a week, but the load is low at around 30%. Though the combustion load was raised to about 85%, the NOx concentration remained almost constantly high at 346 ppm as converted to 5% O_2, regardless of the loading rate.

The combustion chamber load and the combustion chamber section load were high, as well as the air ratio, resulting in the high NOx concentration.

Conceivable countermeasures include optimization of the air ratio, recirculation of flue gas, and use of a low-NOx burner.

6) Countermeasures

i) Retrofitting of combustion equipment

Automatic combustion control, low air ratio combustion and flue gas recirculation

ii) Fuel change

(a) Mixed combustion with 50% heavy oil and 50% diesel or natural gas up to the supply start of desulfurized heavy oil

(b) When supply of desulfurized heavy oil is started, it should be used exclusively (100%)

(c) Emulsified combustion of desulfurized heavy oil should be taken into consideration after thorough demonstration tests.

7) Expenses for boiler retrofitting

Rebuilding for flue gas recirculation, low air ratio combustion and automatic control.

i) Foreign portion

		(US$)
(a) Survey and design	1 set	3,900
(b) Flue gas recirculation fan	1 set	8,500
(c) O_2 meter	1 set	3,100
(d) Package and freight	1 set	1,100
(e) Travelling	1 set	3,900
(f) Unexpected expenses (5% of the above)		1,025
Sub-total		21,525

ii) Local portion

			(US$)
(g)	Wind box repair	1 set	7,700
(h)	On-site installation supervision	1 set	1,100
(i)	On-site instruction for test operation	1 set	800
(j)	Customs and other taxes	1 set	3,660
(k)	Warehouse, customs clearance, and domestic freight (incl. IVA)	1 set	605
(l)	IVA (15% excl. i + k)		1,440
	Sub-total		15,305
	Total		US$ 36,830

8) Summary of Control Measures

Table 5.2.11 summarizes the control measures for the Petrochemical Products Factory (C).

Table 5.2.11 Summary of Control Measures for Petrochemical Product Factory (C)

		Current status	Countermeasure		
			A	B	C
Fuel type		Heavy oil	Heavy oil 50% Diesel 50%	Desulfurized heavy oil 100%	Desulfurized heavy oil 100%
Combustion method		-	-	-	Emulsified combustion
Fuel consumption	Heavy oil (10^3 m^3/yr)	0.354	0.177	0.354	0.354
	Diesel (10^3 m^3/yr)	-	0.177	-	-
Emission (ton/yr)	NOx	7.8	4.4	5.6	4.4
	SO_2	21.2	12.5	4.9	4.9
	PM	1.6	1.3	1.3	1.0
Reduction ratio (%)	NOx	-	44	28	44
	SO_2	-	41	73	73
	PM	-	20	20	40
Equipment cost (1,000US$)			36.83	36.83	36.83
Running cost (approx.)(1,000US$)					
Facility depreciation (15-yrs)			2.5	2.5	2.5
Interest (first 5 yrs: 8%)			2.9	2.9	2.9
Maintenance cost (5%)			1.8	1.8	1.8
Heavy oil		27.5	13.7	-	-
Diesel		-	36.4	-	-
Desulfurized heavy oil		-	-	38.5	-
Desulfurized heavy oil emulsion		-	-	-	47.0
Total (1,000US$/yr)		27.5	57.3	45.7	54.2

Alternative B: Applicable after the start of supplying desulfurized heavy oil.
Alternative C: The emulsified combustion of desulfurized heavy oil should be considered after thorough demonstration tests.

5.2.12 Asphalt Plant

1) Name of facility surveyed — Asphalt Kiln (No.1, No.2 and No.3)

2) Specification of facility

Model	Rotary kiln with asphalt mixing chamber (No.1 and No.2)
	Rotary kiln without asphalt mixing chamber (No.3)
Capacity	250 ton/hr (No.1 and No.2)
	200 ton/hr (No.3)
Draft and ventilation	Induced draft (No.1, No.2 and No.3)
Construction and dimensions of furnace	Rotary horizontal type 2,500ø x 12,000L (No.1 and No.2)
	Rotary horizontal type 2,500ø x 8,000L (No.3)
Number of burner	Oil burner: 1 each (No.1, No.2 and No.3)
Furnace pressure	-2 mmAq
Furnace temperature	200°C
Ancillary facility	Bag filter (No.1)
	Wet cyclone (No.2)
	Cyclone and bag filter (No.3)

3) Specification of burner

Model	Low air pressure atomizing type (No.1, No.2 and No.3)
Type of fuel	Diesel (No.1, No.2 and No.3)
Fuel consumption	1,500 l/hr (No.1 and No.2)
	1,000 l/hr (No.3)
Fuel pressure	1 kg/cm^2g
Atomizing pressure	1,000 mmAq (air)

4) Analytical data of flue gas

i) No. 1 Asphalt manufacturing kiln

(Stack sampling data) 14:00/Load is approx. 50% of rating

NOx (ppm)*	167	Particulate matter (g/Nm^3)	1.9
O_2 (%)	16.7	Flue gas temperature (°C)	104
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	13.8
CO_2 (%)	2.6		

(Emission)

	kg/hr
NOx	3.7
SO_2**	15
Particulate	76

NOx at rated operation is estimated to be 185 ppm (8.2 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

ii) No. 2 Asphalt manufacturing kiln

(Stack sampling data) 12:00/Load is approx. 50% of rating

NOx (ppm)*	217	Particulate matter (g/Nm^3)	3.0
O_2 (%)	16.2	Flue gas temperature (°C)	96
CO (%)	0.05	Combustion chamber outlet O_2 (%)	12.4
CO_2 (%)	3.7		

(Emission)

	kg/hr
NOx	3.7
SO_2**	15
Particulate	83

NOx at rated operation is estimated to be 240 ppm (8.2 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

iii) No. 3 Asphalt manufacturing kiln

(Stack sampling data) 13:30/Load is approx. 80% of rating

NOx (ppm)*	160	Particulate matter (g/Nm^3)	6.2
O_2 (%)	16.5	Flue gas temperature (°C)	88
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	-
CO_2 (%)	2.9		

(Emission)

	kg/hr
NOx	5.0
SO_2**	17
Particulate	340

NOx at rated operation is estimated to be 160 ppm (6.2 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

5) Observation

Three asphalt kilns are presently in operation in this asphalt mix manufacturing factory for paving roads under the direct control of D.D.F.

This factory is located in a hollow basin of 309 m x 518 m. The volcanic rock from the side walls surrounding the factory is cut out, and petroleum based asphalt is mixed with the crushed stones of 5 - 10 mm and asphalt for paving roads is produced.

Of the 3 plants, No. 1 and No. 2 are the same type and have the same capacity (250 ton/hr). The raw material, crushed stones, is introduced at the location of the low air pressure atomizing burner in the rotary kiln for drying, and is dried while rotating and moving in the same direction as the flow of the burnt gas (parallel flow type direct drying system with direct flame of 900°C and combustion gas). The asphalt No. 6 heated up between 130°C and 160°C in the rotary kiln is mixed by 7% to make product.

For dust collection, the No. 1 and No 3. plants make use of the bag filter, the No. 2 plant makes use of the wet type cyclone. The No. 3 plant dries the crushed stones and asphalt mixing by means of independent systems. The No. 3 rotary kiln is used only for drying employing a counterflow method in which the crushed stones are loaded from the opposite side of the burner, and rotated and shifted to the direction opposite to the flow of combustion gas.

The analysis of flue gas indicate that the quantity of particulate matter emission is extremely large. This is because of scattering of small and minute particles of the raw materials. A horizontal rotary wet cyclone of plant No. 2 is not able to collect dust, such as minute particles of sand sticking to the crushed stones. Bag filters have been installed in No. 1 and No. 3 but the PM emission concentration is 1.9 g/Nm^3 for No. 1 and 6.2 g/Nm^3 for No 3, which are about 10 - 100 times the quantity of a normal factory.

The plant is planning to change the No. 3 rotary kiln to a double-drum type. Although this change will lead to improvement of productivity, no reduction in the dust emission is expected. Effort must be made to prevent the dust emission.

Another problem is the generation of CO observed in No. 2 plant. This could be attributed to defect in combustion by the low pressure atomizing burner. But since the fuel is diesel, and NOx of 217 ppm is comparatively high, the cause is not considered the combustion defect but the process in which petroleum based tar is mixed with crushed stones inside the kiln. In other words, there is a possibility that when the combustion gas comes in contact with tar inside the furnace, part of the tar vaporizes or burns and is emitted as HC or CO from the stack. To confirm this, further investigation is necessary. With regard to No. 1 and No. 2 plants, there seems to be inherent defects in the system including poor heating efficiency.

Since this factory is located in a narrow basin, the work environment is also poor, and the particulate matter and noise pollutions around the plant are very severe. The transportation of raw material from outside to the factory is made by 25 ten-ton trucks and 6 forty-ton trailers, and the transportation of 2,500 tons of products from the factory is done by 200 twelve-ton trucks. In addition, there is a considerable degree of dispersion of dust in the surroundings when it is withdrawn from the dust collector causing severe pollution of the environment.

6) Countermeasures

Although the plant is considering relocation of the crushing process only, relocation of the whole plant is desirable in view of environmental protection.

7) Cost

Roughly estimated at about US$ 3.0 million ; major facilities at US$ 1.2 million and auxiliary facilities at US$ 1.8 million.

5.2.13 Cement Factory

(1) Cement Kiln (No.4)

1) Specification of facility

Model	Rotary kiln with suspension preheater (SP)
Capacity	96 ton/hr
Draft and ventilation	Induced draft
Number of burners	1 for kiln, 4 for SP
Furnace pressure	-2 mmAq
Furnace temperature	1,200°C
Ancillary facility	Gas cooling tower : 1 unit, Electrostatic precipitator: 3 units

2) Specification of burner

Model	Mechanical atomizing dual flow type (Pillard type)
Type of fuel	Heavy oil
Fuel consumption	8,850 l/hr (kiln burner) 1,100 l/hr (SP burner)
Fuel pressure	40 kg/cm^2g (kiln burner)
Primary air pressure	850 mmAq

3) Analytical data of flue gas

(Stack sampling data) 13:20/Load is approx. 90% of rating

NOx (ppm)*	379	Particulate matter (g/Nm^3)	0.43
O_2 (%)	7.5	Flue gas temperature (°C)	143
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	6.5
CO_2 (%)	22.1***		

(Emission)

	kg/hr
NOx	66
SO_2**	–
Particulate	43

NOx at rated operation is estimated to be 385 ppm (74 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

*** Includes CO_2 generated through drying of raw materials ($CaCO_3$) etc.)

4) Observation

This is the only cement plant in the metropolitan area. The plant asserts that a sufficient care is taken to prevent air pollution. However, the high NOx and PM concentrations (respectively, 379 ppm and 0.43 g/Nm^3) must be reduced. Especially, the high PM concentration, despite the use of the electrostatic precipitator, may mean either poor performance or poor maintenance of the precipitator.

Furthermore, this rotary kiln is provided with a suspension preheater, but its unit fuel consumption of 1,030,000 kcal/ton is higher than the average of Japanese rotary kilns equipped with a pre-calciner by 300,000 kcal/ton, or 30%; hence more energy should be saved. The comparatively high O_2 concentration of 6.3 to 8.2% in the flue gas before the precipitator suggests excessively high air ratio combustion. The O_2 concentration should be maintained.

5) Countermeasures

i) Retrofitting of combustion equipment

(a) Installation of a precalciner on S.P. kiln (30% reduction of unit fuel consumption)

(b) Low air ratio combustion

(c) Installation of electrostatic precipitator

ii) Fuel change

(a) Mixed combustion with 50% heavy oil and 50% natural gas until the supply start of desulfurized heavy oil

(b) Mixed combustion with 50% desulfurized heavy oil and 50% natural gas after the supply start of desulfurized heavy oil

iii) Continuous monitoring of the flue gas by installing the NOx, SO_2 and O_2 telemeters.

6) Expenses for facility retrofitting

A precalciner should be installed between the existing suspension preheater and the kiln, and a new duct for introducing the hot air from the clinker cooler should be installed. As the addition of the precalciner will increase the output more than 20%, the clinker cooler should be remodelled.

Tentative cost estimation is as follows.

i) Foreign portion

		(US$)
(a)	Preheater (incl. foundation and tower)	13,850,000
(b)	Clinker cooler (remodelling and new ducting	3,850,000
(c)	Electrostatic precipitator	4,620,000
	Sub-total	22,320,000

Total 22,320,000 x 2 = US$ 44,640,000

With this retrofitting, the unit fuel consumption per SP kiln may be reduced by about 30%; from the present 1,030,000 kcal/ton to 700,000 kcal/ton. Note that the above retrofitting costs are only a rough estimate for normal installation. They need adjustment depending on the degree of difficulty of the work and change in material costs according to the availability of local materails.

7) Expenses for telemetric monitoring system of the flue gas of the SP kiln

NOx, SO_2, O_2 telemeters for constant monitoring of the flue gas are to be installed.

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	7,700
(b)	NOx, SO_2, O_2, instrumentation	3 sets	177,900
(c)	Auxiliary units	3 sets	60,000
(d)	Data logger	1 set	17,900
(e)	Installation work on-site supervision	1 set	8,500
(f)	On-site instruction for test operation	1 set	4,700
(g)	Package and freight	1 set	38,800
(h)	Travelling	1 set	12,200
(i)	Unexpected expenses (5% on the above)		16,390
	Sub-total		344,090

ii) Local portion

			(US$)
(j)	Materials	1 set	6,300
(k)	Survey assistant	1 set	1,600
(l)	Installation expenses	1 set	6,500

(m)	Test operation and adjustment	1 set	1,900
(n)	Vehicle rental	1 set	3,300
(o)	Customs and other taxes	1 set	69,830
(p)	Warehouse, customs clearance, land freight (incl. IVA)	1 set	5,200
(q)	IVA (15% excl. o and p)		2,940
	Sub-total		97,570
	Total		US$ 441,660

(Telephone installation work and central reception system are not included.)

(2) Cement Material Dryer (No.8)

1) Specification of facility

Model	Hot air heater
Capacity	180 ton/hr
Draft and ventilation	Balanced draft
Structure of furnace	Horizontal cylindrical furnace
Number of burner	1 unit
Furnace pressure	-25 mmAq
Furnace temperature	670°C
Ancillary facility	Electrostatic precipitator, 1 unit

2) Specification of burner

Model	Gas-oil mixed combustion (Gas: ring type, Oil: Y-jet type)
Type of fuel	Natural gas (Currently, only natural gas is burned.)
Fuel consumption	740 Nm^3/hr
Fuel pressure	1 kg/cm^2g

3) Analytical data of flue gas

(Stack sampling data) 15:00/Load is approx. 87% of rating

NOx (ppm)*	112	Particulate matter (g/Nm^3)	<0.0001
O_2 (%)	17.3	Flue gas temperature (°C)	95
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	16.6
CO_2 (%)	1.5		

(Emission)

	kg/hr
NOx	1.5
SO_2**	–
Particulate	<0.0029

NOx at rated operation is estimated to be 385 ppm (74 kg/h).

* Converted to oxygen concentration of 5%.

** Calculated from analytical value of fuel

4) Observation

This system introduces blasts at about 670°C to the crusher during the process of crushing limestone, one of the cement raw materials, and simultaneously dries the powder which initially contains 3.5% moisture. The system then discharges the 95°C flue gas to the outside via a cyclone and an electrostatic precipitator.

The NOx and the PM concentrations (respectively, 112 ppm and <0.0001 g/Nm^3) present virtually no problem; especially the low PM concentration may be ascribed to the high performance and satisfactory maintenance of the electrostatic precipitator, in contrast to those of the electrostatic precipitator for the rotary kiln.

The existing three raw material drying furnaces currently burn only natural gas, but reportedly, there is a plan to reconvert them to oil burning in the near future. When this plan is implemented, NOx reduction will become necessary even when desulfurized heavy oil is used. Therefore, instead of equipment investment for NOx reduction, continuing use of natural gas is desirable.

5) Countermeasures

No countermeasures seem necessary.

(3) Summary of Control Measures

Table 5.2.13 summarizes the control measures for the Cement Factory.

Table 5.2.13 Summary of Control Measures for the Cement Factory (A)

		Current status	Countermeasure A	Countermeasure B
Fuel type		Heavy oil	Heavy oil 50%	Desulfurized heavy oil 50%
		Natural gas	Natural gas 50%	Natural gas 50%
Fuel consumption	Heavy oil (10^3 m^3/yr)	174.96	64.15	64.15
	Natural gas (10^6 m^3/yr)	12.44	76.59	76.59
Emission (ton/yr)	NOx	1,330.5	785.1	785.1
	SO_2	7,348.3	2,309.4	1,026.4
	PM	848.0	84.8	84.8
Reduction ratio (%)	NOx	-	41	41
	SO_2	-	69	86
	PM	-	90	90
Equipment cost (1,000US$)	Equipment expenses		44,640.0 (1)	44,640.0 (1)
	NOx, SO_2 telemeter		441.6	441.6
Running cost (approx.)(1,000US$)				
Facility depreciation (15-yrs)			3,005.5	3,005.4
Interest (first 5 yrs: 8%)			3,606.5	3,606.5
Maintenance cost (5%)			2,254.1	2,254.1
Heavy oil		13,568.3	4,974.9	-
Diesel		1,036.7	6,382.5	6,382.5
Desulfurized heavy oil		-	-	6,982.3
Total (1,000US$)		14,605.0	20,223.4	22,230.8

Alternative B: Applicable when the supply of desulfurized heavy oil is started.
Note: (1) The introduction of precalciners to the two SP kiln systems is expected to save energy by 30% for each system.

5.2.14 Glass Factory (A)

1) Name of facility surveyed — Glass Melting Furnace (B)

2) Specification of facility

Model	Tank oven
Capacity	230 ton/day
Draft and ventilation	Forced draft
Size of furnace	$6,600^W \times 15,000^D \times 1,500^H$
Number and layout of burners tank,	Air/heavy oil burners: 18 for melting 2 for working tank
Furnace pressure	+0.03 mmAq
Furnace temperature	1,536°C
Ancillary facility	Recuperator (30 → 637°C)

3) Specification of burner

Model	Exterior mixing high pressure air atomizing type
Type of fuel	Heavy oil
Fuel consumption	70 l/hr x 20 burners
Fuel pressure	2 kg/cm^2g
Atomizing pressure	2 kg/cm^2g (air)

4) Analytical data of flue gas

(Stack sampling data) 13:30/Load is approx. 75% of rating

NOx (ppm)*	570	Particulate matter (g/Nm^3)	0.76
O_2 (%)	2.9	Flue gas temperature (°C)	810
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	–
CO_2 (%)	17.4		

(Emission)

	kg/hr
NOx	15
SO_2**	74
Particulate	8.6

NOx at rated operation is estimated to be 580 ppm (15 kg/hr).

* Converted to oxygen concentration of 5%.

** Calculated from analytical value of fuel

5) Observation

This is a tank oven for glass bottle manufacture, with 20 heavy oil burners with air atomization. The air is preheated in a recuperator type heat exchanger.

The recuperator type preheater is common with small ovens around 10 ton/day, but is very rare for medium and large ovens. Since heat is exchanged through metal walls in a recuperator, the air temperature is restricted by the material; the upper limit is around 800°C (1,000°C in special cases). In contrast, regenerative heat exchangers using brick as the heat exchange media can preheat to 1,000 to 1,250 °C and give higher thermal efficiency. However, since the NOx concentration is lower at lower preheated temperatures, the recuperator type preheater makes the NOx concentration lower. The plant personnel are making reasonable efforts to reduce NOx through appropriately low O_2 combustion; as shown in Table 4.2.2 in the text, the NOx concentration measured during the previous JICA study at 1,858 ppm had been reduced to about 1/3, or 570 ppm at the time of the present survey.

The plant is now planning to generate power by the waste heat boiler through recovery and utilization of flue gas heat. However, as glass material dust generated in the high temperature oven is expected to be deposited in the boiler tube, etc. as the temperature drops, this will eventually block the gas passage. Unless this can be prevented, it will be hard to realize this plan.

Since a large amount of glass fume is generated as described above, adoption of simple denitration will present a problem. Therefore, reduction of furnace loading through appropriate combustion control is desirable as a NOx control measure.

This factory wants to change fuel to natural gas, and agreed to cut heavy oil consumption by 30% during the period from January 23 to February 28, 1991.

6) Countermeasures

i) Retrofitting of combustion equipment

(a) Low air ratio combustion by continuous monitoring of the flue gas O_2

(b) Reduction of the combustion chamber load; increase of chamber ceiling height for larger capacity and increase of radiation surface area, and reduction of combustion load below 70,000 kcal/m^3•hr. If heat becomes insufficient for the process, NOx-free electric heaters should desirably be used as a supplementary heat source.

(c) Reduction of unit fuel consumption through improvement of thermal insulation on furnace ceiling

(d) Use of raw material with a low nitrate content

(e) *Installation of electrostatic precipitator*

(f) Study of gas atomizing combustion

ii) Fuel change

(a) Mixed combustion with 50% heavy oil and 50% diesel or natural gas until the start of supply of desulfurized heavy oil

(b) When supply of desulfurized heavy oil supply is started, it should be used exclusively (100%).

iii) Constant monitoring of the flue gas by installing the NOx, SO_2 and O_2 telemeters.

7) Expenses for installation of electrostatic precipitator (EP)

Installation of EP with quick gas cooling tower on the flue of glass melting furnace

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	8,500
(b)	Electrostatic precipitator	1 set	930,800
(c)	Blower	1 set	28,500
(d)	On-site work supervision	1 set	7,700
(3)	On-site instruction for test operation	1 set	7,700
(f)	Travelling	1 set	12,700
(g)	Unexpected expenses (5% on the above)		49,800
	Sub-total		1,045,700

ii) Local portion

		(US$)
(h) Duct fabrication	1 set	20,800
(i) Foundation	1 set	2,200
(j) Installation work	1 set	9,300
(k) On-site instruction for test operation	1 set	800
(l) Work vehicle	1 set	3,100
(m) Customs and other taxes	1 set	263,550
(n) IVA (15% excl. m)		5,430
Sub-total		305,180
Total		US$ 1,350,880

(Since freightage differs with freight package conditions, the freightage and customs expenses are not included.)

8) Installation of the NOx, SO_2, O_2 telemeters for constant monitoring of the flue gas

Expenses for telemeter instrumentation system on the flues of No.A and B glass melting furnaces

i) Foreign portion

		(US$)
(a) Survey and design	1 set	6,200
(b) NOx, SO_2, O_2, instrumentation	2 sets	118,600
(c) Auxiliary units	2 sets	41,100
(d) Data logger	1 set	17,900
(e) Installation work on-site supervision	1 set	8,500
(f) On-site instruction for test operation	1 set	4,700
(g) Package and freight	1 set	25,900
(h) Travelling	1 set	11,900
(i) Unexpected expenses (5% on the above)		11,740
Sub-total		246,540

ii) Local portion

		(US$)
(j) Materials	1 set	4,200
(k) Survey assistant	1 set	1,300
(l) Installation expenses	1 set	4,400

(m)	Test operation and adjustment	1 set	1,400
(n)	Vehicle rental	1 set	2,200
(o)	Customs and other taxes	1 set	41,690
(p)	Warehouse, customs clearance, land freight (incl. IVA)	1 set	3,250
(q)	IVA (15% excl. o and p)		2,030
	Sub-total		60,470
	Total		US$ 307,010

(Telehone installation work and central reception system are not included.)

Note: The temperature of the flue gas from glass melting furnaces is high and heavily loaded with dust produced through scattering and evaporation of raw materials. When sampling the gas, its swift cooling, dust removal and other pretreatments are required.

9) Summary of Control Measures

Table 5.2.14 summarizes the control measures for the Glass Factory (A).

Table 5.2.14 Summary of the Control Measures for Glass Factory (A)

		Current status	countermeasure	
			A	B
Fuel type		Heavy oil	Heavy oil 50% Diesel 50%	Desulfurized heavy oil 100%
Fuel consumption	Heavy oil (10^3 m^3/yr)	20.52	10.26	20.52
	Diesel (10^3 m^3/yr)	-	10.26	-
Emission (ton/yr)	NOx	222.9	124.8	178.3
	SO_2	1,231.2	718.2	328.3
	PM	127.8	6.4	6.4
Reduction ratio (%)	NOx		44	20
	SO_2		41	73
	PM		95	95
Equipment cost (1,000US$)	Equipment expenses		2,701.76	2,701.76
	NOx, SO_2 telemeter		307.01	307.01
Running cost (approx.)(1,000US$)				
Facility depreciation (15-yrs)			200.6	200.6
Interest (first 5 yrs: 8%)			240.7	240.7
Maintenance cost (5%)			150.4	150.4
Heavy oil		1,591.3	795.7	-
Diesel		-	2,111.3	-
Desulfurized heavy oil		-	-	2,233.5
Total (1,000US$/yr)		1,591.3	3,498.7	2,825.2

Alternative B: Applicable after the supply of desulfurized heavy oil is started.

5.2.15 Glass Factory (B)

1) Name of facility surveyed — Melting furnace for glass fiber (No.2)

2) Specification of facility

Model	Tank oven
Capacity	0.28 ton/hr
Draft and ventilation	Forced draft
Dimensions of furnace	$1{,}981^W \times 6{,}552^D \times 762^H$
Number of burners	24 air/gas burners 2 oxygen/gas burners
Furnace pressure	+0.05 mmAq
Furnace temperature	1,544°C
Ancillary facility	Recuperator (30 → 670°C)

3) Specification of burner

Model	Gas: Nozzle mix system
Type of fuel	Natural gas
Fuel consumption	Air/gas burner 235 Nm^3/hr O_2/gas burner 320 Nm^3/hr
Fuel pressure	1.5 kg/cm^2g

4) Analytical data of flue gas

(Stack sampling data) 14:30/Load is approx. 125% of rating

NOx (ppm)*	1,226	Particulate matter (g/Nm^3)	0.48
O_2 (%)	5.4	Flue gas temperature (°C)	843
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	0.9
CO_2 (%)	11.4		

(Emission)

	kg/hr
NOx	9.6
SO_2**	---
Particulate	1.9

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

5) Observation

This is a glass fiber manufacturing tank oven. It uses 24 air/natural gas burners and 2 oxygen/natural gas burners. Its interior temperature rises to a high level of 1,544°C. Accordingly, its flue gas contains 1,226 ppm of NOx, and 0.48 g/Nm^3 of particulate matter, which are abnormally high for a gas burning furnace. This results from the high furnace temperature.

This high NOx concentration is caused by thermal NOx generated at high temperature. The particulate matter is considered to be composed of vaporized raw materials for glass, such as alkali and silica.

The 155 kW electric heater installed recently in the tank oven has improved the productivity to over 100%.

Since a large amount of fume is generated from the glass materials, adoption of simple in-furnace denitration may present a problem. Therefore, the reduction of NOx generation should be brought about through the combustion control measures. These measures are employed in a large glass factory in Japan. The use of the oxygen/natural gas burners should be abandoned since they generate a large amount of thermal NOx as described above.

6) Countermeasures

i) Retrofitting of the combustion equipment

(a) Low air ratio combustion through combustion control

(b) Reduction of combustion chamber load; increase of chamber ceiling height for larger capacity and increase of radiation surface area, and reduction of combustion load below 70,000 kcal/m^3hr. If heat becomes insufficient for the process, NOx-free electric heaters should desirably be used as supplementary heat source.

(c) Installation of sets of primary and secondary burners to replace all the existing burners with the parallel adoption of the off-stoichiometric combustion mode.

(d) Reduction of unit fuel consumption through improvement of thermal insulation of furnace ceiling

(e) Installation of electrostatic precipitators

ii) Others

Use of raw material with a low nitrate content

7) Expenses for installation of electrostatic precipitator (PE) (per 1 unit)

Installation of the EP with quick gas cooling tower on the flue of glass melting furnace

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	8,500
(b)	Electrostatic precipitator	1 set	516,000
(c)	Blower	1 set	16,000
(d)	On-site work supervision	1 set	7,700
(3)	On-site instruction for test operation	1 set	7,700
(f)	Travelling	1 set	12,700
(g)	Unexpected expenses (5% on the above)		85,300
	Sub-total		653,900

ii) Local portion

			(US$)
(h)	Duct fabrication	1 set	13,900
(i)	Foundation	1 set	1,600
(j)	Installation work	1 set	16,000
(k)	Test operation and adjustment	1 set	800
(1)	Work vehicles rent	1 set	3,100
(m)	Customs and other taxes	1 set	146,200
(n)	IVA (15% excl. m)		5,300
	Sub-total		186,900
	Total		US$ 840,800

Since freightage differs with freight package conditions, the freightage and customs expenses are not included.

Note: For other two furnaces of the same type as the No.2 melting furnace, the same retrofitting expenses (US$ 1,681,600 for 2 units) are applicable.

8) Summary of Control Measures

Table 5.2.15 summarizes the control measures for the Glass Factory (B).

Table 5.2.15 Summary of Control Measures for Glass Factory (B)

		Current status	countermeasure
Fuel type		Natural gas	Natural gas
Equipment, etc.		-	Combustion load reduction and EP installation
Fuel consumption	Natural gas (10^6 m^3/yr)	17.376	17.376
Emission (ton/yr)	NOx	230.3	115.1
	PM	44.5	2.2
Reduction ratio (%)	NOx		50
	PM		95
Equipment cost (1,000US$)			2,522.4 (Note)
Running cost (approx.)(1,000US$)			
Facility depreciation (15-yrs)			168.2
Interest (first 5 yrs: 8%)			201.8
Maintenance cost (5%)			126.1
Natural gas		1,448.0	1,448.0
Total (1,000US$/yr)		1,448.0	1,944.1

Note: The amount includes the retrofitting expenses of US$1,681,600 for the two unsurveyed melting furnaces of the same type as the surveyed No.2 furnace.

5.2.16 Glass Factory (C)

(1) Melting Furnace for Glass Bottles (No.84)

1) Specification of facility

Model	Tank oven
Capacity	400 ton/day
Draft and ventilation	Forced draft
Dimensions of furnace (Hot air heater)	$10{,}000^{W} \times 16{,}500^{D} \times 2{,}200^{H}$
Number of burners	Air/gas burners: 24 (12 sets, with 2 burners per set)
Furnace pressure	+0.9 mmAq
Furnace temperature	1,490°C
Ancillary facility	Regenerative heat exchanger (30 → 1,000°C)

2) Specification of burner

Model	Gas: Partial pre-mix type burner
Type of fuel	Natural gas
Fuel consumption	2,500 Nm^3/hr
Fuel pressure	400 mmAq

3) Analytical data of flue gas

(Stack sampling data) 16:00/Load is approx. 92% of rating

NOx (ppm)*	644	Particulate matter (g/Nm^3)	0.39
O_2 (%)	6.6	Flue gas temperature (°C)	418
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	5.8
CO_2 (%)	10.7		

(Emission)

	kg/hr
NOx	35
SO_2**	–
Particulate	11

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

This plant is an integrated bottle and cup production plant handling processes of shaping, gradual cooling, and printing and labeling of bottles.

This furnace is called the No. 84 furnace, one of three tank ovens in the plant for manufacturing glass bottles. It is provided with 24 air/natural gas burners (12 sets). The temperature in the furnace is 1,490°C. Two burners form a set facing each others. The distance between the nozzle tips is about 300 mm, and the jet gases from the opposing nozzles collide with each others. Since the energy from the jet is killed, the mixing of combustion air is very poor.

It is observed in the furnace that glass surface is coated with the flame accompanied by the the black smoke. Naturally for a normal low temperature furnace, smoke will be generated, but since the temperature of this furnace is above 1,400°C, combustion is complete within the furnace or in the heat regenerating room.

The air ratio is high (oxygen 5.8%) for a high temperature furnace, and if the amount of oxygen is reduced to less than 2.0%, then the NOx concentration can be reduced.

The PM concentration was high at 0.39 g/Nm^3 showing the characteristics of glass tank ovens, and this is because of partial vaporization of the glass material due to high temperature.

In this furnace, flit glass is being manufactured and the quantity of cullet introduced is 25 - 30%. The unit fuel consumption is 125 x 10^4 kcal/hr. The No 81 furnace is an improved version with complete separation of the melting tank and the working tank. This has resulted in lowering the unit fuel consumption to 96 x 10^4 kcal/hr. In the future, efforts should be made to save energy by reducing the fuel consumption in this No.84 furnace by such measure of improvement applied to No.81 furnace.

Introduction of simple denitration with ammonia injection is technically difficult since the flue gas contains a large amount of fume. Therefore, it is important to reduce thermal NOx through appropriate combustion control along with the reduction of fuel consumption by strengthening of thermal control that also contributes to reducing the NOx emission. Since the location of the burners in this furnace is not appropriate as described above, rationalization of the incidence angle of the burners and the shape of nozzles is necessary as well as trying change of the burner location to confirm possible increase of NOx generation due to collision of flames.

5) Countermeasures

i) Retrofitting of the combustion equipment

(a) Low air ratio combustion through continuous monitoring of the flue gas O_2

(b) Burner location change to avoid flame collision and adoption of the off-stoichiometric combustion mode.

(c) Reduction of combustion chamber load: increase of chamber ceiling height for larger capacity and increase of radiation surface area, and reduction of combustion load below 70,000 kcal/m^3hr. If heat becomes insufficient for the process, NOx-free electric heaters should desirably be used as supplementary heat source.

(d) Installation of electrostatic precipitator.

ii) Fuel saving and others

(a) Reduction of fuel consumption through improvement of thermal insulation of furnace ceiling

(b) Use of raw material with a low nitrate content

iii) Continuous monitoring of the flue gas through the installation of the NOx, SO_2, O_2 telemeters

6) Expenses for retrofitting combustion equipment

Installation of the EP with quick gas cooling tower on the flue of glass melting furnace

i) Foreign portion

		(US$)
(a) Survey and design	1 set	8,500
(b) Electrostatic precipitator	1 set	1,215,400
(c) Blower	1 set	63,100

(d)	On-site work supervision	1 set	7,700
(3)	On-site instruction for test operation	1 set	7,700
(f)	Travelling	1 set	12,700
(g)	Unexpected expenses (5% on the above)		65,800
	Sub-total		1,380,900

ii) Local portion

			(US$)
(h)	Duct fabrication	1 set	30,000
(i)	Foundation	1 set	3,850
(j)	Installation work	1 set	15,400
(k)	On-site instruction for test operation	1 set	800
(l)	Work vehicle	1 set	1,000
(m)	Customs and other taxes	1 set	352,700
(n)	IVA (15% excl. m)		7,660
	Sub-total		411,410
	Total		US$ 1,792,310

Note: Since freightage differs with freight package conditions, the EP freightage from shipping place to destination and customs expenses are not estimated here.

7) Reduction ratio

i) Through retrofitting of combustion equipment

NOx: 20%

PM: 95%

ii) Through fuel saving

NOx: 40%

(2) Glass Melting Furnace (No.82)

1) Specification of facility

Model	Tank oven
Capacity	200 ton/day

Draft and ventilation	Forced draft
Size of furnace	$6,706^{W} \times 10,973^{D} \times 2,095^{H}$
Number and layout of burner	2 units x 10 sets (natural gas burner)
Furnace pressure	1 ~ 1.2 mmH_2O
Furnace temperature	1,452°C
Ancillary facility	Regenerative heat exchanger

2) Specification of burner

Model	Nozzle mix burner
Type of fuel	Natural gas
Fuel consumption	1,840 m^3/hr
Fuel pressure	4.0 kg/cm^2g

3) Analytical data of flue gas

(Stack sampling data) 16:00/ Load is approx. 100% of rating

NOx (ppm)*	736	Particulate matter (g/Nm^3)	0.12
O_2 (%)	6.0	Flue gas temperature (°C)	465
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	2.8
CO_2 (%)	10.5		

(Emission)

	kg/hr
NOx	43
SO_2**	-
Particulate	3.6

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

4) Observation

This furnace is another one of three glass melting tank ovens in this bottle production plant, and is applied with a sufficient heat insulation. The preheated air temperature from the regenerative heat exchanger was sufficiently high and the temperature of the high-temperature zone in the furnace reached 1,450°C. The furnace internal pressure is controlled to 1 - 1.2 mmH_2O and the air ratio is checked three times a day with a portable O_2 meter. There is almost no change in the air ratio as well as fuel input.

The NOx concentration was 736 ppm as converted to 5% O_2. For large glass tank ovens burning heavy oil, the NOx concentration can be reduced by about 20% through gas atomization. Because this oven was changed for gas burning, the effects of the following methods on NOx reduction should be checked in order to establish an optimum condition.

(1) Rationalization of incidence angle and nozzle shape of the gas burner

(2) Attempt to reduce the amount of O_2 further in addition to the O_2 control currently executed

(3) Change of the burner position to check if the NOx generation is increased by collision of flames since side-port type burners are currently installed in the counter firing position.

Since the flue gas contains a large amount of fume, and flue gas denitration is difficult in may ways, thermal NOx reduction efforts by thorough combustion control and further NOx reduction through fuel saving by strengthening thermal control are very important.

5) Countermeasures

i) Retrofitting of the combustion equipment

(a) Low air ratio combustion through continuous monitoring of the flue gas O_2

(b) Burner location change to avoid flame collision and adoption of the off-stoichiometric combustion mode.

(c) Installation of electrostatic precipitator.

ii) Fuel saving and others

(a) Reduction of fuel consumption through improvement of thermal insulation of furnace ceiling

(b) Reduction of combustion chamber load: increase of chamber ceiling height for larger capacity and increase of radiation surface area, and reduction of combustion load below 70,000 kcal/m^3hr. If heat becomes insufficient for the process, NOx-free electric heaters should desirably be used as supplementary heat source.

(c) Use of raw material with a low nitrate content

iii) Continuous monitoring of the flue gas through the installation of the NOx, SO_2, O_2 telemeters

6) Expenses for retrofitting combustion equipment

Installation of the EP with quick gas cooling tower on the flue of glass melting furnace

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	8,500
(b)	Electrostatic precipitator	1 set	1,215,400
(c)	Blower	1 set	63,100
(d)	On-site work supervision	1 set	7,700
(3)	On-site instruction for test operation	1 set	7,700
(f)	Travelling	1 set	12,700
(g)	Unexpected expenses (5% on the above)		65,800
	Sub-total		1,380,900

ii) Local portion

			(US$)
(h)	Duct fabrication	1 set	30,000
(i)	Foundation	1 set	3,850
(j)	Installation work	1 set	15,400
(k)	On-site instruction for test operation	1 set	800
(l)	Work vehicle	1 set	1,000
(m)	Customs and other taxes	1 set	352,700
(n)	IVA (15% excl. m)		7,660
	Sub-total		411,410
	Total		US$ 1,792,310

Note: (1) Since freightage differs with freight package conditions, the EP freightage from shipping place to destination and customs expenses are not estimated here.

(2) At this factory, there are other combustion facilities that are nearly of the same capacity as No.82 furnace and using the same type of fuel, and they are expected in need of similar treatment as the No.82 furnace.

7) Reduction ratio

i) Through retrofitting of furnace

NOx: 20%

PM: 95%

ii) Through fuel saving

NOx: 40%

(3) Installation of the NOx, SO_2, O_2 Telemeters for Constant Monitoring of the Flue Gas

Expenses for installing telemeter system on the flues of No.84, 82, and 81 glass melting furnaces.

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	7,700
(b)	NOx, SO_2, O_2, instrumentation	3 sets	177,900
(c)	Auxiliary units	3 sets	60,000
(d)	Data logger	1 set	17,900
(e)	Installation work on-site supervision	1 set	8,500
(f)	On-site instruction for test operation	1 set	4,700
(g)	Package and freight	1 set	38,800
(h)	Travelling	1 set	12,200
(i)	Unexpected expenses (5% on the above)		16,390
	Sub-total		344,090

ii) Local portion

			(US$)
(j)	Materials	1 set	6,300
(k)	Survey assistant	1 set	1,600
(l)	Installation expenses	1 set	6,500
(m)	Test operation and adjustment	1 set	1,900
(n)	Vehicle rental	1 set	3,300
(o)	Customs and other taxes	1 set	69,830

(p)	Warehouse, customs clearance, land freight (incl. IVA)	1 set	5,200
(q)	IVA (15% excl. o and p)		2,940
	Sub-total		97,570
	Total		US$ 441,660

(Telephone installation work and central reception system are not included.)

Note: The temperature of the flue gas from the glass melting furnaces is high and heavily loaded with dust produced through scattering and evaporation of the raw material. When sampling the gas, pretreatments such as rapid cooling and removal of dust is required.

(4) Summary of Control Measures

Table 5.2.16 summarizes the control measures for the Glass Factory (C).

Table 5.2.16 Summary of Control Measures for Glass Factory (C)

		Current status	Control measure
Fuel type		Natural gas	Natural gas
Fuel consumption	Natural gas (10^6 m^3/yr)	64.98	38.99
Emission (ton/yr)	NOx	213.4	102.4
	PM	42.8	2.1
Reduction ratio (%)	NOx		52 (1)
	PM		95
Equipment cost (1,000US$)	Equipment cost		5,376.93 (2)
	Nox, SO_2 telemeter		441.66
Running cost (approx.)(1,000US$)			
Facility depreciation (15-yrs)			387,.9
Interest (first 5 yrs: 8%)			465.5
Maintenance cost (5%)			290.9
Natural gas		5,415.0	3,249.2
Total (1,000US$/yr)		5,415.0	4,393.5

Note: (1) Reduction ratio attained by the burner retrofitting and fuel saving
(2) Costs for 3 units of electrostatic precipitator

5.2.17 Rubber Products Factory

1) Name of facility surveyed — Boiler for processing

2) Specification of facility

Model	Water tube boiler
Capacity	10 ton/hr
Draft and ventilation	Forced draft
Dimensions of furnace	$1{,}700^W \times 5{,}588^D \times 2{,}000^H$
Number of burner	1 unit
Furnace pressure	+60 mmAq
Ancillary facility	None

3) Specification of burner

Model	Intermixing type oil burner
Type of fuel	Heavy oil
Fuel consumption	814 l/hr
Fuel pressure	4 kg/cm^2g
Atomizing pressure	5 kg/cm^2g (steam)

4) Analytical data of flue gas

(Stack sampling data) 14:40/Load is approx. 60% of rating

NOx (ppm)*	270	Particulate matter (g/Nm^3)	0.19
O_2 (%)	6.2	Flue gas temperature (°C)	330
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	–
CO_2 (%)	10.5		

(Emission)

	kg/hr
NOx	4.2
SO_2**	42
Particulate	1.5

NOx at rated operation is estimated to be 300 ppm (7.7 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

5) Observation

This is a factory which manufactures tires for automobiles.

One boiler is used at present, with a 10 ton/hr capacity, for steam heating as required in the molding of tires. It has automatic controls, rare for

Mexican boilers, and the combustion load of the boiler changes rapidly according to the variation in load for heating tires. On the day of the diagnostic survey, the load was small, and varied between 40 to 60% of the rated load. The oxygen concentration in the flue gas at this time was 6-10%, which is quite high. Therefore, careful adjustment of the air ratio is necessary for operation.

6) Countermeasures

i) Retrofitting of the combustion equipment

(a) Low air ratio combustion through combustion control system
(b) Flue gas recirculation by installing the flue gas fan

ii) Fuel change

(a) Mixed combustion with 50% heavy oil and 50% diesel or natural gas up to the supply start of desulfurized heavy oil

(b) When supply of desulfurized heavy oil is started, it should be used exclusively (100%)

(c) Emulsified combustion of desulfurized heavy oil should be taken into consideration after thorough demonstration tests.

7) Expenses for retrofitting combustion equipment

Retrofitting for flue gas recirculation and low air ratio combustion

i) Foreign portion

		(US$)
(a) Survey and design	1 set	7,700
(b) Flue gas recirculation fan	1 set	17,000
(c) Combustion control system and electric instrumentation	1 set	23,100
(d) Package and freight	1 set	8,100
(e) Travelling	1 set	4,800
(f) Unexpected expenses (5% on above)		3,040
Sub-total		63,740

ii) Local portion

(g)	Burner fabrication	1 set	7,700
(h)	Duct and fan installation work	1 set	1,600
(i)	Electric instrumentation installation work	1 set	4,700
(j)	Local installation on-site supervision	1 set	3,100
(k)	On-site instruction for test operation	1 set	1,100
(l)	Customs and other taxes	1 set	12,300
(m)	Warehouse, customs clearance, and land freight (incl. IVA)	1 set	1,020
(n)	IVA (15% excl. l + m)		2,730
	Sub-total		34,250
	Total		US$ 97,990

8) Summary of control measures

Table 5.2.17 summarizes the control measures for the Rubber Products Factory.

Table 5.2.17 Summary of Control Measures for the Rubber Products Factory

		Current Status	Control measures		
			A	B	C
Fuel type		Heavy oil	Heavy oil 50% Diesel 50%	Desulfurized heavy oil 100%	Desulfurized heavy oil 100%
Combustion method					Emulsified combustion
Fuel Consumption	Heavy oil (10^3m^3/yr)	3.7	1.85	3.7	3.7
	Diesel (10^3m^3/yr)	-	1.85	-	-
Emission (ton/yr)	NOx	16.6	9.3	12.0	9.3
	SO_2	222.0	131.0	59.9	59.5
	PM	11.3	7.9	7.9	4.0
Reduction ratio (%)	NOx		44	28	44
	SO_2		41	73	73
	PM		30	30	65
Equipment cost (1,000US$)			97.99	97.99	97.99
Running cost (approx.)(1,000US$/yr)					
Facility depreciation (15 yrs)			6.5	6.5	6.5
Interest (first 5 yrs: 8%)			7.8	7.8	7.8
Maintenance cost (5%)			4.9	4.9	4.9
Heavy oil		286.9	143.5	-	-
Diesel		-	380.7	-	-
Desulfurized heavy oil		-	-	402.7	-
Desulfurized heavy oil emulsion		-	-	-	490.8
Total (1,000 US$/yr)		286.9	543.4	421.9	510.0

Alternative B: Applicable after the start of supplying desulfurized heavy oil.
Alternative C: Emulsified combustion should betaken into consideration after thorough demonstration tests.

5.2.18 Paper Factory

1) Name of facility surveyed — Power generation boiler (No. 1 and No. 2)

2) Specification of facility

Model	Water tube boiler
Capacity	12.9 ton/hr (No. 1), 15.9 ton/hr (No. 2)
Draft and ventilation	Balanced draft
Dimensions of furnace	$3{,}524^{W} \times 3{,}500^{D} \times 3{,}000^{H}$ (No. 2)
Number of burners	2 for No. 1 boiler, 3 for No. 2 boiler
Furnace pressure	-5 mmAq (No. 1), -2 mmAq (No. 2)
Ancillary facility	Recuperator (30 to 200°C) (estimated)

3) Specification of burner

Model	Oil: Y-jet type
Type of fuel	Heavy oil
Fuel consumption	1,100 l/hr (No. 1) 1,350 l/rh (No. 2)
Fuel pressure	4 kg/cm^2g (estimated)
Atomizing steam pressure	5 kg/cm^2g (estimated)

4) Analytical data of flue gas

(Stack sampling data) 14:30/Load is approx. 70% of rating

NOx (ppm)*	249	Particulate matter (g/Nm^3)	0.44
O_2 (%)	11.5	Flue gas temperature (°C)	218
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	10.0
CO_2 (%)	6.2		

(Emission)

	kg/hr
NOx	10
SO_2**	100
Particuate	15

NOx at rated operation is estimated to be 260 ppm (15 kg/hr).

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

5) Observation

This is an used paper recycling plant. A 12.9 ton/hr boiler and a 15.9 ton/hr boiler are connected to one stack, so only one set of data is available. The boiler steam is first used for power generation, and then, at a reduced pressure, for drying the recycled paper.

The flue gas analysis shows a high O_2 concentration of 10%; this indicates an improper air ratio for combustion. The PM concentration is relatively high for heavy oil combustion at 440 mg/Nm^3. This results in slightly visible smoke. This high PM concentration is caused firstly by poor heavy oil atomization generating many large unburned particles in the furnace. Secondly, it is caused by poor fuel-air mixing; this causes long flames as the O_2 concentration is reduced in the flue gas. This means poor burner performance generating more smoke under the appropriate air ratio. The burners must be improved.

The low fuel preheating temperature is also a factor for poor combustion.

6) Countermeasures

i) Retrofitting of the combustion facility

(a) Low air ratio combustion through combustion control system
(b) Flue gas recirculation by installing flue gas fan
(c) Remodelling into low NOx burner

ii) Fuel change

(a) Mixed combustion with 50% heavy oil and 50% diesel or natural gas up to the supply start of desulfurized heavy oil

(b) When supply of desulfurized heavy oil is started, it should be used exclusively (100%)

(c) Emulsified combustion of desulfurized heavy oil should be taken into consideration after thorough demonstration tests.

7) Expenses for retrofitting No. 1 boiler

Retrofitting for flue gas recirculation and low NOx burner installation and low air ratio combustion, and for automatic operation control

i) Foreign portion

			(US$)
(a)	Survey and design	1 set	9,300
(b)	Low NOx burners (1,100 l/hr)	2 units	80,000
(c)	Flue gas recirculation fan	1 set	12,300
(d)	Combustion control system and electric instrumentation	1 set	30,800
(e)	Local work on-site supervision	1 set	5,400
(f)	On-site instruction for test operation	1 set	5,400
(g)	Package and freight	1 set	14,600
(h)	Travelling	1 set	11,200
(i)	Unexpected expenses (5% on above)		8,450
	Sub-total		177,450

ii) Local portion

(j)	Burner removal and installation	1 set	1,600
(k)	Duct fabrication (incl. heat insulation)	1 set	10,000
(l)	Duct and fan installation work	1 set	2,000
(m)	Electric instrumentation installation work	1 set	13,900
(n)	On-site instruction for test operation	1 set	700
(o)	Customs and other taxes	1 set	38,900
(p)	Warehouse, customs clearance, and land freight (incl. IVA)	1 set	2,750
(q)	Freight for ducts, crane rental	1 set	2,000
(n)	IVA (15% excl. o + p)		4,530
	Sub-total		76,380
	Total		US$ 253,830

8) Expenses for retrofitting No.2 boiler

Retrofitting for flue gas recirculation and low NOx burner installation and low air ratio combustion

i) Foreign portion

		(US$)
(a) Survey and design	1 set	11,600
(b) Low NOx burners	3 units	124,700
(c) Flue gas recirculation fan	1 set	13,100
(d) Combustion control system and electric instrumentation	1 set	38,500
(e) Local work on-site supervision	1 set	5,400
(f) On-site instruction for test operation	1 set	5,400
(g) Package and freight	1 set	16,200
(h) Travelling	1 set	11,200
(i) Unexpected expenses (5% on above)		11,300
Sub-total		237,400

ii) Local portion

(j) Burner removal and installation	1 set	2,000
(k) Duct fabrication (incl. heat insulation)	1 set	13,000
(l) Duct and fan installation work	1 set	2,300
(m) Electric instrumentation installation work	1 set	15,400
(n) Local work on-site supervision	1 set	2,000
(o) On-site instruction for test operation	1 set	800
(p) Customs and other taxes	1 set	56,000
(q) Warehouse, customs clearance, and land freight (incl. IVA)	1 set	3,850
(r) Duct, etc. freight, crane rental	1 set	2,000
(s) IVA (15% excl. n + o)		5,300
Sub-total		102,650
Total		US$ 340,050

9) Summary of control measures

Table 5.2.18 summarizes the control measures for the Paper Factory.

Table 5.2.18 Summary of Control Measures for the Paper Factory

		Current Status	Control measures		
			A	B	C
Fuel type		Heavy oil	Heavy oil 50% Diesel 50%	Desulfurized heavy oil 100%	Desulfurized heavy oil 100%
Combustion method					Emulsified combustion
Fuel Consumption	Heavy oil (10^3m^3/yr)	8.948	4.474	8.948	8.948
	Diesel (10^3m^3/yr)	-	4.474	-	-
Emission (ton/yr)	NOx	52.6	25.8	33.1	25.8
	SO_2	536.9	316.7	144.9	144.9
	PM	78.9	47.3	63.1	31.6
Reduction ratio (%)	NOx		51	37	51
	SO_2		41	73	73
	PM		40	20	60
Equipment cost (1,000US$)			593.8	593.8	593.8
Running cost (approx.)(1,000 US$/yr)					
Facility depreciation (15 yrs)			39.6	39.6	39.6
Interest (first 5 yrs: 8%)			47.5	47.5	47.5
Maintenance cost (5%)			19.7	29.7	29.7
Heavy oil		693.9	347	–	–
Diesel		–	920.7	–	–
Desulfurized heavy oil		–	–	973.9	–
Desulfurized heavy oil emulsion		–	–	–	1187
Total (1,000 US$/yr)		693.9	1,384.5	1,090.7	1,303.8

Alternative B: Applicable after the start of supplying desulfurized heavy oil.
Alternative C: Emulsified combustion should be taken into consideration after thorough demonstration tests.

5.2.19 Paper Products Factory (A)

1) Name of facility surveyed — Boiler for processing

2) Specification of facility

Model	Water tube boiler
Capacity	9.4 ton/hr
Draft and ventilation	Balanced draft
Size of furnace	$1{,}700^W \times 5{,}588^D \times 2{,}000^H$
Number of burners	2
Furnace pressure	-30 mmAq
Ancillary facility	None

3) Specification of burner

Model	Oil: Y-jet type
Type of fuel	Heavy oil
Fuel consumption	808 l/hr
Fuel pressure	3 kg/cm^2g
Atomizing pressure	4.5 kg/cm^2g (steam)

4) Analytical data of flue gas

(Stack sampling data) 14:00/Load is approx. 100% of rating

NOx (ppm)*	185	Particulate matter (g/Nm^3)	0.28
O_2 (%)	10.3	Flue gas temperature (°C)	255
CO (%)	<0.05	Combustion chamber outlet O_2 (%)	5.6
CO_2 (%)	7.4		

(Emission)

	kg/h
NOx	3.6
SO_2**	48
Particulate	4.0

* Converted to oxygen concentration of 5%

** Calculated from analytical value of fuel

5) Observation

This plant manufacturers cartons and carboads from recycled paper. The boiler is used to heat and dry the recycled paper. It is rather an outmoded type of boiler, consisting of the outer brickwork and the drum and the water tubes incorporated within. Although the blower for forced draft and the flue gas induction fan are used for balanced drafting, no air preheater is installed. Atomization of the Y-jet type oil burner is poor resulting in carbon deposits on the burner tile, high O_2 concentration in the flue gas, and large unburnt particles floating in the boiler. Naturally, incomplete combustion is observed.

The boiler operation is manually controlled, and smoke is generated from time to time with fluctuation of air ratio caused by the fluctuation of boiler loading.

6) Countermeasures

i) Retrofitting of the combustion facility

(a) Automatic operation control with the combustion control system and electric instrumentation system

(b) Low air ratio combustion by constant monitoring of the flue gas O_2

(c) Burner remodelling and flue gas recirculation by installing the flue gas fan

(d) Two-stage combustion

ii) Fuel change

(a) Mixed combustion with 50% heavy oil and 50% diesel or natural gas up to the supply start of desulfurized heavy oil

(b) When supply of desulfurized heavy oil is started, it should be used exclusively (100%)

(c) Emulsified combustion of desulfurized heavy oil should be taken into consideration after thorough demonstration tests.

7) Expenses for retrofitting boiler (per one unit)

Retrofitting for 2-stage combustion, flue gas recirculation, low air ratio combustion, low NOx burner installation and, and for automatic operation control

i) Foreign portion

		(US$)
(a) Survey and design	1 set	7,700
(b) Low NOx burner	1 set	63,100
(c) Flue gas recirculation fan	1 set	9,300
(d) Combustion control system and electric instrumentation	1 set	23,100
(e) Package and freight	1 set	11,900

(f)	Travelling	1 set	4,800
(g)	Unexpected expenses (5% of the above)		6,500
	Sub-total	126,400	

ii) Local portion

			(US$)
(h)	Burner and duct removal	1 set	800
(i)	Duct fabrication (incl. heat insulation)	1 set	7,700
(j)	Duct, fan and burner installation work	1 set	2,000
(k)	Electric instrumentation installation work	1 set	4,700
(l)	Local work on-site supervision	1 set	3,100
(m)	On-site instruction for test operation.	1 set	600
(n)	Customs and other taxes	1 set	30,200
(o)	Warehouse, customs clearance, and land freight (incl. IVA)	1 set	2,230
(p)	Duct, etc. freight and crane rental	1 set	2,000
(q)	IVA (15% excl. n + o)		3,130
	Sub-total		56,460
	Total		US$ 182,860

Note: There are 4 boilers, of which one is out of operation, and all are of the same type as the No. 1 boiler. The same retrofitting cost (US$ 548,580 for 3 sets) can be estimated.

8) Portable O_2 meter

US$ 2,400 (excl. customs duty, customs clearance expenses and domestic freight)

9) Summary of control measures

Table 5.2.19 summarizes the control measures for the Paper Products Factory (A).

Table 5.2.19 Summary of Control Measures for the Paper Products Factory (A)

		Current Status	Control measures		
			A	B	C
Fuel type		Heavy oil	Heavy oil 50% Diesel 50%	Desulfurized heavy oil 100%	Desulfurized heavy oil 100%
Combustion method		–	–	–	Emulsified combustion
Fuel Consumption	Heavy oil ($10^3 m^3$/yr)	11.0	5.5	11.0	11.0
	Diesel ($10^3 m^3$/yr)	–	5.5	–	–
Emission (ton/yr)	NOx	81.5	45.6	58.7	45.6
	SO_2	660	389	178	178
	PM	90.5	72.4	72.4	54.3
Reduction ratio (%)	NOx	–	44	28	44
	SO_2	–	41	73	73
	PM	–	20	20	40
Equipment cost (1,000US$)			733.84	733.84	733.84
Running cost (approx.) (1,000US$/yr)					
Facility depreciation (15 yrs)			48.9	48.9	48.9
Interest (first 5 yrs: 8%)			58.7	58.7	58.7
Maintenance cost (5%)			36.7	36.7	36.7
Heavy oil		853.1	426.5	–	–
Diesel		–	1,131.8	–	–
Desulfurized heavy oil		–	–	1,197.3	–
Desulfurized heavy oil emulsion		–	–	–	1,459.2
Total (1,000 US$/yr)		853.1	1,702.6	1,341.6	1,603.5

Alternative B: Applicable after the start of supplying desulfurized heavy oil.
Alternative C: Emulsified combustion should be taken into consideration after thorough demonstration tests.
Note: 100% loading for No. 1 boiler and 50% loading for other three boilers are assumed.