No.

THE UNITED MEXICAN STATES

THE STUDY ON THE AIR POLLUTION CONTROL PLAN OF STATIONARY SOURCES IN THE METROPOLITAN AREA OF THE CITY OF MEXICO

FINAL REPORT

SUMMARY

SEPTEMBER 1991

JAPAN INTERNATIONAL COOPERATION AGENCY

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ACRONYMS

DF	:	Distrito Federal (Federal District)
EM	:	Estado de Mexico (State of Mexico)
MCEM	:	Municipios Conurbados del Estado de Mexico (17 cities of the State of Mexico within AMCM)
AMCM	:	Area Metropolitana de la Ciudad de Mexico (Metropolitan Area of the City of Mexico = DF + MCEM)
DDF	:	Departamento del Distrito Federal (Department of Federal District)
GEM	:	Gobierno del Estado de Mexico (Government of the State of Mexico)
SEDUE	:	Secretaria de Dasarrollo Urbano y Ecologia (Ministry of Urban Development and Ecology)
SHCP	:	Secretaria de Hacienda y Credito Publico (Ministry of Finance and Public Credit)
SPP	:	Secretaria de Programacion y Presupuesto (Ministry of Planning and Budget)
SECOFI	:	Secretaria de Comercio y Fomento Industiral (Ministry of Commerce and Industrial Development)
SEMIP	:	Secretaria de Energia, Minas e Industria Paraestatal (Ministry of Energy, Mines and Public Industry)
PEMEX	:	Petroleos Mexicanos (Mexican Petroleum)
CFE	:	Comision Federal de Electricidad (Federal Commission for Electricity)
IMP	:	Instituto Mexicano del Petroleo (Mexican Institute of Petroleum)
IIE	:	Instituto de Investigaciones Electricas (Institute of Electrical Investigation)

Table of Contents

CHAPTER 1 INTRODUCTION

1.1 Background of the Study

During 1970s, the Metropolitan Area of the City of Mexico (Area Metropolitana de la Ciudad de Mexico : AMCM) experienced remarkable motorization and industrial expansion. At the same time, the problem of air pollution became serious due to the increased emissions of air pollutants and the unfavorable conditions of the topography and meteorology.

The Mexican Government had been working long against the air pollution problem since the start of monitoring air quality of AMCM in 1960. Activities in pollution control have been intensified from the beginning of 1980s. The Federal Environmental Protection Law was promulgated in 1982. A legal measure was introduced in 1985 in order to promote industrial relocation out of AMCM. A network of automatic air quality monitoring system of 25 measuring stations began its operation in January 1986, thereby giving clearer information on air pollution in AMCM. In February 1986, a Presidential Decree of "21 Concrete Measures for Air Pollution Control" was promulgated and the fight against the air pollution was greatly intensified.

In March 1988, the Federal Environmental Protection Law of 1982 was replaced by the General Law for Ecological Balance and Environmental Protection which defined more clearly the responsibilities of various governmental agencies involved in pollution control activities.

A major aspect of air pollution control of automobiles in Mexico is the establishment of the emission standards. This is to be applied by types and models of automobiles coupled with production and supply of unleaded gasoline. For reduction of air pollutant emissions from factories, measures such as improvement in fuel quality and increased supply of natural gas have been gradually promoted.

In order to achieve smooth implementation of a wide variety of air pollution control measures including those stated above, serious efforts have been made also in building up social consensus. It was represented by the publication of a report in October 1990 called the "Integrated Program Against Air Pollution in the Metropolitan Area - A Common Agreement".

This program of 41 air pollution control measures clarified the significance of each measure, time schedule and the responsible agency for execution of each measure.

Through the development of various programs for air pollution control, it can be said that the programs for air pollution control of automobiles such as emission regulations of new automobiles and introduction of the inspection system of exhaust gas for existing automobiles have provided a long-term prospect of improvement in the automobile air pollution.

On the other hand, regarding stationary sources of air pollution, technical characteristics of a wide variety of the stationary sources in AMCM have not been well understood, and therefore, technological studies for application of effective measures have not been sufficiently conducted. The prospect to abate industrial air pollution is yet to be established.

The purpose of this Study is to provide an assistance for abating air pollution being caused by the stationary sources in AMCM.

The Scope of Work (SW) for the Study was agreed between the authorities concerned in the Government of Mexico (GOM) and Japan International Cooperation Agency (JICA) in August 1989, and the Study was started in February 1990.

1.2 Objective and Scope of the Study

The objective of this Study is to formulate a plan for the control of air pollution caused by stationary sources in the Metropolitan Area of the City of Mexico (AMCM) from both technical and economic points of view.

At the initial stage of the Study, the target pollutants for the Study included sulfur oxides (SOx), as well as nitrogen oxides (NOx) and smoke and soot (or particulate matter, PM). However, shortly after the start of the Study, the Study team was informed that the Mexican Government decided to implement the following programs aiming at reduction of SOx emissions.

(1) In order to produce heavy oil with the sulfur content at 0.8% which will replace heavy oil of the 3.0% - 3.5% sulfur content currently used in AMCM, a hydro-desulfurization plant is to be constructed in the Tula refinery, and the supply of the desulfurized heavy oil will be started in 1995.

(2) The two thermoelectric power plants in AMCM are to increase the use of natural gas as the primary fuel until start of supplying the desulfurized havy oil. The desulfurization of flue gas is not to be employed because of the cost.

Since implementation of these programs is considered to reduce much of the SOx emissions from stationary sources, the scope of the present Study was modified by placing emphasis of the control measure study on NOx and smoke and soot (PM).

1.3 Execution of the Study

1.3.1 Study Organization

The executing agencies of the Study in the Mexican Government are as follows:

1) Ministry of Urban Development and Ecology (SEDUE), Bureau of Ecology

2) Department of Federal District (DDF), General Directorate of Urban Reordination and Ecological Protection

3) Government of the State of Mexico (GEM), State Commission of Ecology

The executing agency of Japan is Japan International Cooperation Agency (JICA), which executes the Study in consultation with the Ministry of International Trade and Industry (MITI) and the Ministry of Foreign Affairs (MOFA).

For execution of the Study, JICA selected the Study Team and the above Mexican authorities organized the Mexican counterpart team.

1.3.2 Study Period

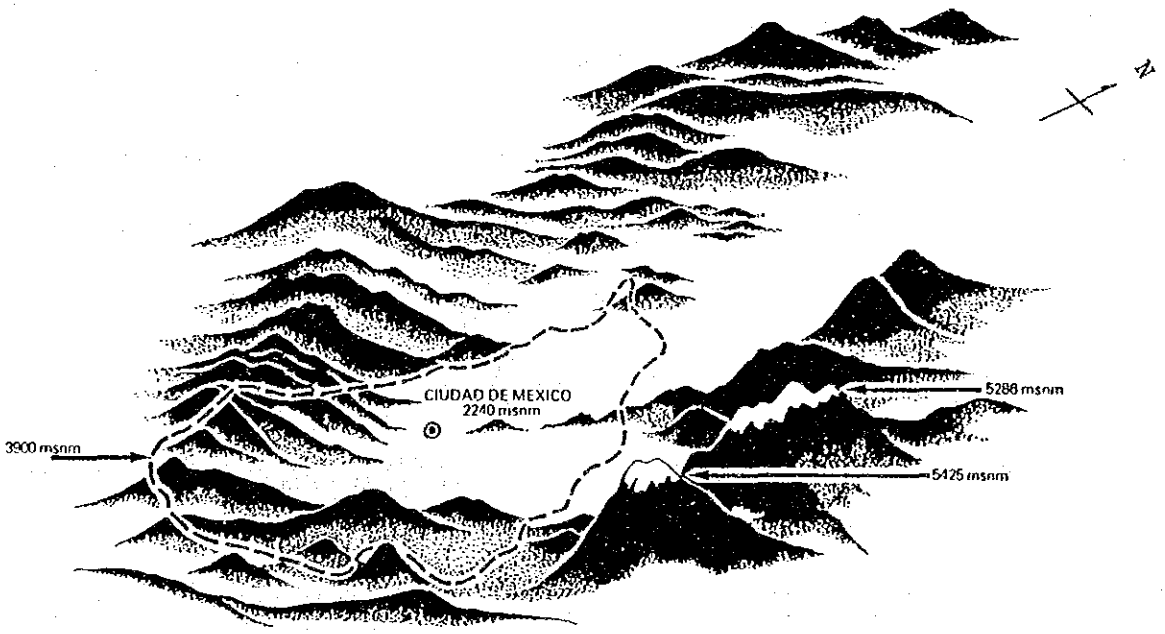
The Study started in February 1990, and completed in September 1991.

CHAPTER 2 BASIC CONDITIONS CONCERNING STATIONARY AIR POLLUTION SOURCES IN THE METROPOLITAN AREA

2.1 Geographical Condition

Mexico City is located in the Valley of Mexico in the southern corner of the Central Highland. The altitude of the lowest part of the valley is 2,240m above the sea level. The valley stretches toward north and is surrounded by mountain ranges as shown in Figure 2.1.1.

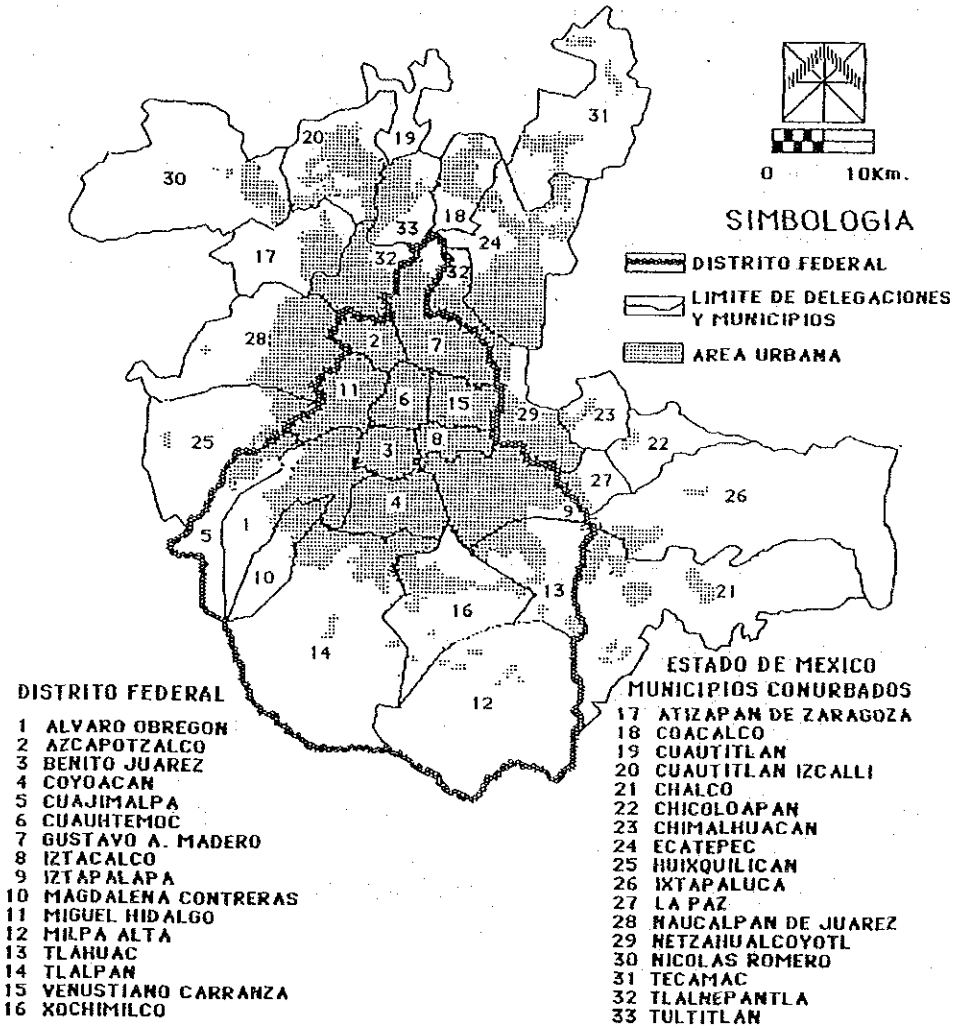
The climate is warm and relatively dry. The daily average temperature is between 10°C and 23°C. The highest monthly average temperature is 17.4°C in May, and the lowest one is 12.1°C in January. The annual precipitation is 725mm, most of which concentrates during the period from May to October. During the dry season (or winter season), a higher frequency of forming thermal inversion and a limited precipitation tend to aggravate air pollution.



Source: BRAVO, A.H., LA CONTAMINACION DEL AIRE EN MEXICO, UNIVERSO VEINTIUNO, 1987.

Figure 2.1.1 Conceptual Sketch of the Valley of Mexico

The Mexico City Metropolitan Area (AMCM) consists of all the sixteen DELEGACIONES of the Federal District (DF) and the seventeen MUNICIPIOS of the State of Mexico (hereinafter referred to as "MCEM", the acronym of MUNICIPIOS CONURBADOS DEL ESTADO DE MEXICO), as shown in Figure 2.1.2. The total area of AMCM is about 3,615km^2, of which DF is about 1,505km^2 and MCEM is about 2,110km^2. The area of Tokyo, for reference, is about 1,758km^2 excluding its islands. The same area of AMCM is often referred to as "ZMCM" in literature. But in this report, the acronym "AMCM" will be used after the definition given by "PROGRAMA GENERAL DE DESARROLLO URBANO DEL DISTRITO FEDERAL 1987-1988".



Source: PROGRAMA INTEGRAL CONTRA LA CONTAMINACION ATMOSPERICA Un Compromiso Común, October 1990

Figure 2.1.2 Mexico City Metropolitan Area (AMCM) and Its Urbanized Area

2.2 Population and Industry

2.1.1 Population

According to the general census published in March 1990, the population of AMCM is about 14,990,000, or 18.4% of the total population of Mexico with about 81,140,000. Of the total population of 14.99 million in AMCM, 8.24 million, or 55% reside in DF, and 6.75 million, or 45% reside in MCEM.

While the annual population growth in DF during 1980-1990 was only 0.26%, it maintained a high rate in MCEM at 4.25%. However, the rate for the AMCM total during the same period at 1.85% is slightly below the national average of 1.88%. These figures indicate that the population inflow from other regions, observed significantly during 1960s and 1970s, has been restrained in recent years.

The areas where the population has decreased during the last 10 years are the highly urbanized and commercialized six DELEGACIONES in DF: CUAUHTEMOC, MIGUEL HIDALGO, BENITO JUAREZ, VENUSTIANO CARRANZA, GUSTAVO A. MADERO, and IZTACALCO.

Meanwhile, the population has more than doubled in the six MUNICIPIOS of the State of Mexico: ATIZAPAN DE ZARAGOZA, CHALCO, CHICOLOAPAN, CHIMALHUACAN, IXTAPALUCA, and TULTITLAN.

As indicated above, inhabitants in AMCM have been moving from the central areas to the surrounding areas.

The population of AMCM in the future is forecasted by the Government of Mexico (GOM) to increase at an annual rate of 1.4%, and to exceed 20 million in 2010.

According to the projections by the Study Team in that the trend of decreasing rate of population growth was taken into account, the population in 2010 is expected to be at about 18 million and it will be close to the saturated population. This is shown in Figure 2.2.1.

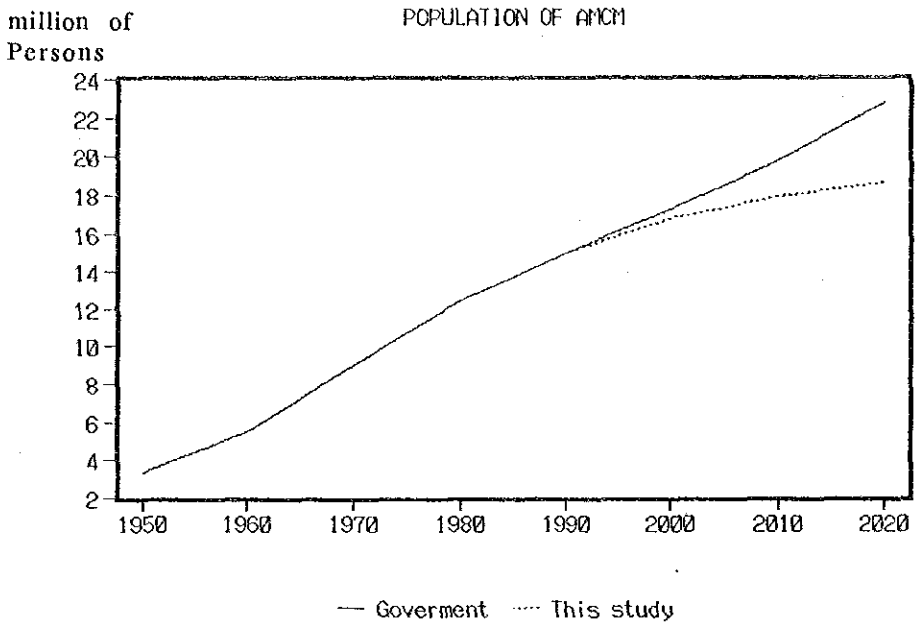


Figure 2.2.1 Change in the Population in AMCM

2.2.2 Industry

The GDP of Mexico in 1989 was about US$200 billion according to the temporary report. The economic scale of AMCM is considered to be of US$80 billion or 40% of the national GDP.

According to the sectoral distribution of GDP in AMCM, agriculture constitutes 0.09% of the total, mining, manufacturing, construction and electricity together 30.0%, transportation and communication 3.8%, and services 65.7%. Industrial structure of AMCM, with a large share of the service sector and a very small share of agriculture, is distinctively different from the national average, showing characteristics of major cities.

2.2.3 Factories

In 1985, the number of the establishments located in AMCM was about 34,000, of which 24,000 were in DF and 10,000 were in MCEM.

The number of factories in DF increased rapidly during 1960s, and reached a peak in 1975 at about 30,000. Then it turned to decrease. During 10 years until 1985, it decreased by 5,000. The decreasing trend is expected to be continuing at present in DF.

On the other hand, the number of factories in MCEM steadily increased from about 1,000 in 1960 to about 10,000 in 1985, ten times in 25 years. According to a survey in 1986 by the government of EM, however, the number in MCEM was about 8,000. This indicates that the number of factories has turned to decrease also in MCEM.

As of 1990, the number of factories located in AMCM may be estimated at about 27,000 considering the past trend.

Among the types of factories in AMCM, food manufacturing factories occupy the highest percentage with 26% of the total number of factories. They are followed by metal products factories at 14%, wood products at 9%, apparel at 8%, publishing and printing at 8%, general machinery at 6%, rubber and plastic at 4%, textile at 4%, and electric machinery at 3%.

As regards scale distribution of factories, the number of large scale factories in AMCM are estimated to be 600 to 700, and medium scale factories estimated to be 900 to 1,100, and large and medium together 1,500 to 1,800.

2.3 Energy

Mexico shares about 5% in the world total of crude oil production, and basically self-supplies crude oil and natural gas. About a half of the produced crude oil is exported and its 10% equivalent of refined products is imported. Production, refining, exportation and importation of petroleum energy are unitarily carried out by Petroleos Mexicanos (PEMEX), a government organization.

After extraction, crude oil and natural gas are transported through pipelines to eight oil refineries and nine gas processing plants.

In AMCM, there was one refinery called the 18 de Marzo Refinery. But this refinery was closed on March 18, 1991, and now it is functioning only as the fuel supply center for AMCM.

This refinery was not capable of producing enough refined products to meet the demand in AMCM. Therefore, pipelines have been installed to supply the balance from other refineries and gas plants. Distillated products, such as diesel and LPG, come from the POZA RICA refinery, 237km apart from the 18 de Marzo refinery, and the TULA refinery, 82km from the 18 de Marzo refinery. Natural gas is piped to the 18 de Marzo refinery from VENTA DE CARPIO, 31km from the refinery.

Heavy oil for the stationary users in AMCM is an exception. It was entirely produced in the 18 de Marzo refifinery. Main features of this heavy oil is : 1) sulfur content is 3.0 - 3.5%, 2) heaviest type has a high viscosity at about 1,000 cSt.

The distillation products are distributed from the 18 de Marzo refinery by pipeline to three AMCM distribution centers, from where tank cars transport these products to dealers. Major users, such as two power plants, an airport and some large factories, are connected by pipelines from the 18 de Marzo refinery.

Natural gas is supplied through the gas pipeline network to users in AMCM. This network has 363 control stations beyond which distribution pipes are installed at expense of users.

According to the Ministry of Energy, Mines and Public Industry (SEMIP), the total consumption of energy in AMCM in 1986 was 121.55×10^{12}kcal. Its breakdown by sectors and by kinds of energy is shown in Table 2.3.1.

Table 2.3.1 Energy Consumption by Sectors in AMCM (1986)

(Unit: 10^{12}kcal)

	Transportation	Electric Generation	(1) Industries	Services	(2) Others	Total
Gasoline	43.35	-	-	-	-	43.35
Diesel	10.12	0.03	6.34	0.48	-	16.97
Heavy oil	-	9.88	1.90	0.42	-	12.21
LPG	-	-	-	1.01	11.06	12.07
Natural gas	-	6.83	16.94	-	0.62	24.40
Electricity	0.60	-	5.81	2.02	4.12	12.55
Total	54.07	16.74	30.99	3.93	15.80	121.55

Source : PROGRAMA INTEGRAL DE LUCHA CONTRA LA CONTAMINACION ATMOSFERICA EN LA ZONA METROPOLITANA DE LA CIUDAD DE MEXICO, SEDUE, PEMEX, Edo. Mex, DDF, CFE, September 1989.

Note : (1) Includes PEMEX
(2) Residential and public facilities

When the energy consumption figures shown in Table 2.3.1 are summed up for stationary and mobile sectors, the stationary sector makes up 55.5% and the mobile sector (transportation) makes up 45.5% of the total consumption. The kind of energy whose consumption is the largest in the stationary sector is natural gas at about 20% of the total energy consumption in AMCM. It is followed by heavy oil (10%), LPG (9.9%), electricity (9.8%) and diesel (5.7%).

Table 2.3.2 shows the annual actual quantity and projected quantity of supply of major fuels in AMCM informed by PEMEX. Figure 2.3.1 shows the same for natural gas, heavy oil and diesel.

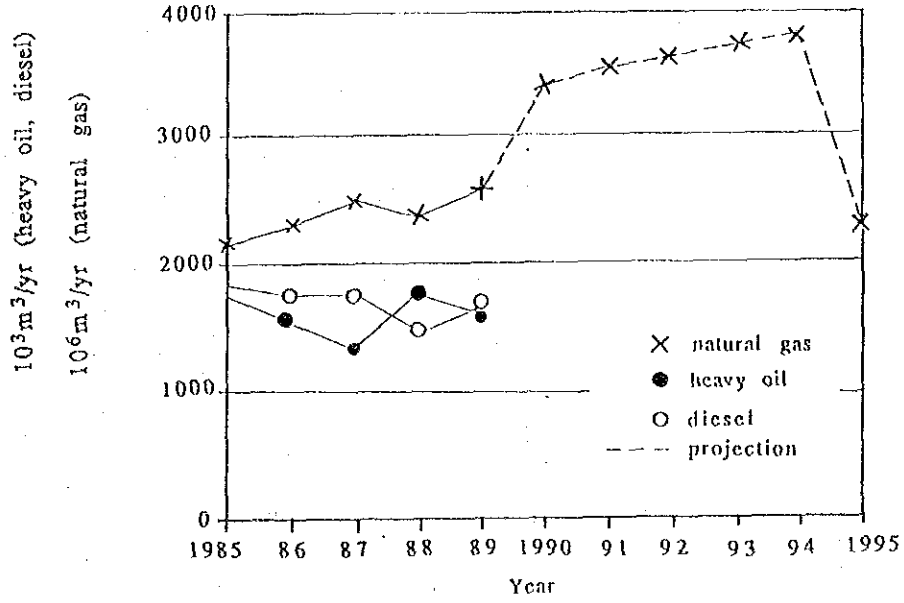
Table 2.3.2 Annual Supply of Major Fuels in AMCM

Kind of Fuel	Unit	Actual Amount of Supply					Projected Amount of Supply					
		1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995
Heavy oil	10^3m^3	1,747	1,567	1,329	1,776	1,607						
Natural gas	10^6m^3	2,155	2,304	2,506	2,371	2,584	3,411	3,541	3,627	3,721	3,824	2,274
Diesel	10^3m^3	1,838	1,752	1,753	1,453	1,654						
Gasoline	10^3m^3					5,524						

Source : PEMEX, March 8, October 24 and 26, 1990.

Note : (1) Original units were converted to the metric units.

(2) In 1995, low sulfur heavy oil will be abailable by $1.306 \times 10^3 m^3/yr$ (22,500 BPCD). This amount is equivalent to $1,550 \times 10^6 m^3$ of natural gas. From that year on, supply of natural gas will be increased again towards the present level.



Source: PEMEX, 1990

Figure 2.3.1 Annual Supply of Major Fuels in AMCM

The supply of natural gas has been increased in the recent years mainly for two thermo-electirc power plants in AMCM as a measure for air pollution mitigation. Towards several years ahead, the supply of natural gas will be further increased to be used in large-scale factories. At present, a project is going on to construct a plant in TULA for hydro-desulfurization of heavy oil. The desulfurized heavy oil is to be supplied to the stationary users in AMCM. PEMEX expects to start supplying this fuel in 1995, and therefore, supply of natural gas is to be reduced by equivalent amount in that year.

Table 2.3.3 summarizes the quantity of heavy oil, natural gas and diesel consumed at stationary sources in AMCM in 1989. Since the consumption figure of diesel in stationary sources was not statistically available, it was estimated based on the ratio for the stationary sector obtained from Table 2.3.1 and the ratio for the same in the national level.

Table 2.3.3 Consumption of Major Fuels in Stationary Sources in AMCM (1989)

Kinds of Fuel		Unit	Consumption	Users
Heavy oil	Heavy	10^3m^3	702(1)	power plants, 18 de Marzo refinery
	Ecological	10^3m^3	905	factories, service and commercial establishments
	Sub-total	10^3m^3	1,607	
Natural gas		10^6m^3	2,584	power plants, refinery, factories, etc.
Diesel	Special	10^3m^3	410 - 660(2)	factories, service and commercial establishments

Note: (1) Breakdown of this amount is as follows (unit: 10^3m^3):
Valle de Mexico power plant : 496.8
Jorge Luque power plant : 163.6
18 de Marzo refinery : 41.4
(2) Estimated amount

2.4 Present Status of Pollution Control of Stationary Sources

2.4.1 Industrial Relocation Policy

The industrial development policy of the Government of Mexico is aimed at promotion of investments in the preferential industrial sectors, development of small-sized industries, and balanced regional development, by providing principles and stimulative measures for relocation of industries. This policy also has an effect in diverging the industries contributing to air pollution to localities.

To implement this policy, industrial sectors and regions are categorized according to preference. Favorable treatment is applied in taxation and energy prices for the preferential industiral sectors and regions.

Preferential industrial sectors are those related to improvement of the industrial structure in Mexico such as import-substituting industrial sectors and Mexican capital goods production sectors. Meanwhile, thirty-five industrial sectors are designated as the sectors whose relocation out of AMCM is desirable in terms of prevention of environmental pollution.

Regional preferences for industrial siting are classified into the following five zones.:

I. National preferential region

- Zone I-A : Coastal industrial zones; 4 large industrial ports
- Zone I-B : Other cities having industrial development potentials especially in the States of Tabasco and Chiapas

II. State preferential region

- Zone II : Cities designated by relevant aurthorities as industial centers of states

III. Controlled region

- Zone III-A : DF and its peripheral cities
- Zone III-B : Densely populated regions under influence of Zone III-A : States of Hidalgo, Mexico, Morelos, Puebla and Tlaxcala

In the controlled regions, favorable taxation is least applicable and favorable treatment in energy prices is not applicable at all. Especially, in Zone III-A, there is no favorable treatment at all for the major manufacturing industries.

There were 17 factories that moved out of the Zone III-A under the favorable treatment provided by this policy. However, this system is not applied at present because of the budgetary problem.

2.4.2 Favorable Taxation and Credit for Pollution Control Investments

In 1987, a favorable tax system for pollution control investments was introduced that offered 25% of the total pollution control investment to be deductible for the federal tax. About 200 applications were submitted in one year, but this system is suspended at present.

Instead, a low-interest credit system was introduced in August 1990 for the pollution control investments. Eighty percent of the investment amount is financed by NAFINSA, a national bank, ten percent is financed by a managing bank, and remaining ten percent is self-financed. The interest rate is the same level as government bonds. The Government is actively promoting publicity of this system.

2.4.3 Emission Standards for Stationary Sources

The basic law for the protection of the environment in the United Mexican States is the General Law for Ecological Balance and Environmental Protection (LEY GENERAL DEL EQUILIBRIO ECOLOGICO Y LA PROTECCION AL AMBIENTE: LGEEPA) which became effective in March 1988. The rules and regulations for enforcement of LGEEPA for prevention and control of air pollution were also promulgated in November 1988. As required by LGEEPA, the emission standards for air pollution sources have been developed by SEDUE.

The presently effective emission standards for general combustion facilities are laid down according to the kind of fuel used. Since these standards are rather lenient, SEDUE is currently preparing new standards to replace them. The new standards for the emissions of CO, SO_2, NOx and

smoke and soot are to be applied to any combustion equipment depending on its capacity.

2.4.4 Integrated Program Against Air Pollution in the Metropolitan Area

in 1990, a comprehensive air pollution control program entitled "Integrated Program Against Atmospheric Pollution in the Mexico City Metropolitan Zone, A Common Agreement" (hereinafter referred to as "the Program") was established in October 1990. The Program is an outcome of the efforts continued since 1986 when the "Twenty-one measures to control air pollution" was promulgated through the presidential decree. The Program was worked out by the inter-governmental technical secretariat composed of SEDUE, SHCP, SPP, SECOFI, Ministry of Communication and Transport, SEMIP, Ministry of Agriculture and Water Resources, Ministry of Health, DDF, GEM, municipal governments of MCEM, PEMEX, CFE, and IMP.

The strategy of the Program is to integrate air pollution control activities in the following sectors.

1. Petroleum industry
2. Transportation
3. Private industries and service establishments
4. Thermoelectric power generation
5. Reforestation and ecological restoration
6. Investigation, environmental education and social communication

The Program contains a total of 41 concrete air pollution control measures involving the above sectors. Executing organization(s) are specified for each of these measures.

Among the 41 concrete measures, the following 17 measures are aimed to control stationary sources of air pollution.

Measure No.3	Production of low-sulfur heavy oil
Measure No.7	Sulfur recovery in the 18 de Marzo refinery
Measure No.8	Recovery of hydrocarbon vapor and replacement of burners in the 18 de Marzo refinery
Measure No.9	Installation of continuous monitoring devices for stack gas in the 18 de Marzo refinery

Measure No.10 Installation of floating roofs in fuel storage tanks

Measure No.11 Installation of vapor recovery systems at fuel terminals and gasoline stations

Measure No.22 Substitution of natural gas for heavy oil in factories

Measure No.23 Agreement between SEDUE and industries on emission control

Measure No.24 Prohibition of new installation of factory and expansion of processes with high consumption of water or fuels

Measure No.26 Emission control and relocation of foundries

Measure No.27 Installation of continuous exhaust gas monitoring devices

Measure No.28 Improvement of combustion processes and installation of emission control devices in service establishments

Measure No.29 Use of natural gas in the thermoelectric power plants until the supply of low-sulfur heavy oil is started

Measure No.30 Suspension of operation of power generation units at the two power plants in winter

Measure No.31 Installation of continuous exhaust gas monitoring devices in the power plants

Measure No.32 Reforestation of urban area

Measure No.33 Reforestation of rural areas of the Mexico Valley and ecologically influenced areas

2.4.5 Recent Development

(1) Pollution Control Measures for the Winter of 1990/91

The status of air pollution in AMCM in the winter of 1990/91 became severer than normal years, particularly since the middle of December. Major causes for this outcome are believed to be increased traffic volume and traffic congestion, and the status of atmospheric thermal inversion which was observed to be more intense than in normal years.

Against this situation, SEDUE, DDF and GEM collaborated to work out the following measures which were publicly announced by the Head of DDF on January 9, 1991.

1) 300 factories that are considered as major pollution sources take one of the following two measures during the period from January 15 to February 28:

   i) to substitute natural gas or diesel for heavy oil

   ii) to cut plant operation by 30%

2) The best solution to air pollutant emissions from the 18 de Marzo refinery is determined within 10 months

3) All the schools in AMCM are closed on the days when the air pollution has reach to a high level.

4) Traffic of large-size trucks in the central area of AMCM is allowed only at night.

5) Operation of taxies and combis on Saturdays is cut by 50% beginning from January 19.

6) The "No Car Day" program is applied also to the automobiles for group tours and airport services.

7) All the city buses will have a new engine before March 1.

To meet the requirement of 1) above, the 82 factories have changed heavy oil to diesel as of the end of January. Among the factories located on the network of natural gas pipeline, the 16 factories applied for the use of natural gas.

(2) Closure of the 18 de Marzo Refinery

After the announcement of the above measures, SEDUE and PEMEX worked together to elaborate on the permanent solution against pollutant emissions from the 18 de Marzo refinery.

The refinery began its operation in 1933, and many of their oil refining facilities are of old age. Therefore, implementation of the permanent air pollution control measures requires a large amount of capital investment and a long period of time.

It was finally decided by the President of Mexico that the refinery should be closed. All refining operation was stopped as of March 18, 1991.

The 18 de Marzo refinery has been functioning, besides as a refinery, as the sole base of fuel supply for AMCM by distributing distillate fuels transported by pipelines from other refineries. This function is expected to continue. However, the closure of oil refining operation will affect the fuel supply system of AMCM to a considerable extent. Prompt reorganization of the fuel supply system for AMCM is needed.

CHAPTER 3 FUEL CONSUMPTION AND AIR POLLUTANT EMISSIONS FROM STATIONARY SOURCES IN THE METROPOLITAN AREA

3.1 Objects and Method of Investigation

The object sources for the investigation of fuel consumption and pollutant emissions were selected so that they can well represent all the stationary sources in AMCM having a combustion facility emitting air pollutants.

Besides utilizing the results of the past surveyes of SEDUE and DDF, investigations were made through detailed and simplified on-site questionnaires and exhaust gas measurements. The data thus obtained were for about 7,700 establishments, as shown in Table 3.1.1, of which about 1,400 were factories.

Table 3.1.1 Number of Establishments Investigated

Kind of Study	Number of Establishment	Sector
Detailed on-site questionnaire by the JICA Study Team	97 (82)	manufacture, service and commercial
1000 factory questionnaire by SEDUE (in this Study)	969 (935)	manufacture, service and commercial
Existing data of SEDUE	371 (364)	manufacture
DDF's survey *	6,070 (0)	service and commercial
CANAIBAL's survey **	203 (0)	public bath
Total	7,710 (1,381)	

Note: * Survey area limited within DF.
** Survey area limited within DF except 13 bathhouses in MCEM.
( ) Number excluding the service and commercial sector.

The number of manufacturing industrial establishments (hereinafter called "factories")is about 19,000 in DF and about 8,000 in MCEM. When these factories are classified by scales in terms of number of employees, and factories of unknown scale are regarded as of micro-scale, the number of each scale of factories is as shown in Table 3.1.2.

Table 3.1.2 Number of Factories by Scale in AMCM

Area	Large	Medium	Small	Micro	Total
DF (1987)	207	427	3,911	14,770	19,315
MCEM (1986)	379	247	1,637	5,858	8,121
AMCM Total (percentage)	586 (2.1)	674 (2.5)	5,548 (20.2)	20,628 (75.2)	27,436 (100)

The number of the factories at 1,381 covered in this Study is about 5% of the total in AMCM. However, since these factories were sampled in order of largeness in scale, it is considered that a large majority of large and medium scale factories in terms of pollutant emission were covered by this Study.

As regards the service and commercial sector, there are about 191,000 establishments in DF and about 76,000 in the whole State of Mexico. However, the DDF's investigation clarified that there are only some 6,300 establishments or 3.3% of the total in DF that are emitting pollutants. When this ratio is applied to the State of Mexico, the number of the similar establishments is estimated at 2521, i.e., in MCEM less than 2500, making the total in AMCM about 8,800. Since this Study covered about 6,300 of them, more than 70% of those emitting air pollutants in AMCM are considered to be covered by this Study.

Accordingly, information on the total 7710 pollution sources covered by this Study will well represent the characteristics of stationary air pollution sources in AMCM.

3.2 Total Amount of Fuel Consumption and Pollutant Emission

3.2.1 Fuel Consumption

Fuel consumption figures obtained through the various investigations are summarized in Table 3.2.1.

Table 3.2.1 Fuel Consumption at Stationary Sources in AMCM

Kind of Study		Study Team	SEDUE	SEDUE	DDF	CANAIBAL	Total
Number of Sample		97	969	371	6,070	203	7,710
Fuel	Heavy oil ($10^3m^3/yr$)	815	190	36	15	40	1,096
	Diesel ($10^3m^3/yr$)	29	84	8	51	0	172
	Kerosene ($10^3m^3/yr$)	-	16	0	26	-	42
	N. gas ($10^6m^3/yr$)	2,478	735	104	0.2	-	3,317

Table 3.2.1 indicates that, in terms of heat value, heavy oil and natural gas are consumed by large amount.

Main feature of consumption of each fuel is as follows.

1) Heavy oil

Of the total 1,096 x 10^3m^3 shown in Figure 3.2.1, about 75% is used by the 97 establishments surveyed by the Study Team. When the consumption by the 969 establishments (file name: HORNOS) and the 371 establishments (file name: DATGEN) surveyed by SEDUE are added, the percentage becomes 95%.

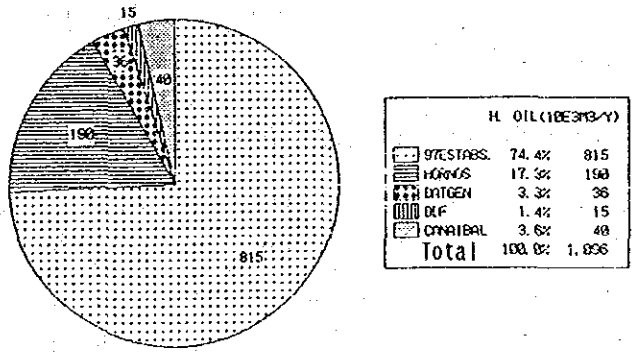


Figure 3.2.1 Heavy Oil Consumption in AMCM

2) Diesel

Although diesel is used by various sectors, its share in the total energy consumption in stationary sources is rather small.

3) Natural gas

As shown in Figure 3.2.2, the 97 establishments surveyed by the Study Team consumed 75% of the total of 3,317 million m^3. When the 1,340 establishments surveyed by SEDUE (HORNOS and DATGEN) are added, the percentage becomes almost 100%.

Similar to heavy oil, natural gas is mostly used by factories. Consumption by service and commercial sector is negligible.

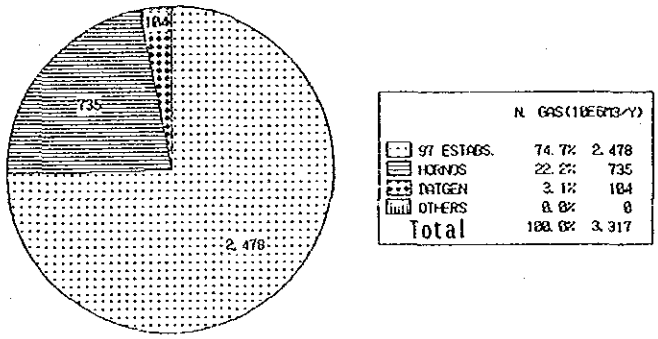


Figure 3.2.2 Natural Gas Consumption in AMCM

3.2.2 Pollutant Emissions

Pollutant emissions obtained through the various investigations are summarized in Table 3.2.2.

Table 3.2.2 Pollutant Emissions from Stationary Sources in AMCM

Kind of Study		Study Team	SEDUE	SEDUE	DDF	CANAIBAL	Total
Number of Sample		97	969	371	6,070	203	7,710
Pollut-ant	NOx (10^3ton/yr)	15.8	3.6	0.6	0.6	0.2	20.8
	SO2 (10^3ton/yr)	55.3	14.6	2.6	1.9	1.7	76.3
	PM (10^3ton/yr)	9.9	0.8	0.1	0.2	0.3	11.3

Note: Pollutant emissions by the use of LPG are not included in the samples of the SEDUE's studies..

The emissions from the 97 establishments survey by the Study Team constitute a large portion of the above totals for NOx, SO_2 and PM as shown in Figures 3.2.3. When the 1340 establishments surveyed by SEDUE are added, the percentage becomes 95%.

The characteristics of emissions of major pollutants are as follows.

1) SO_2

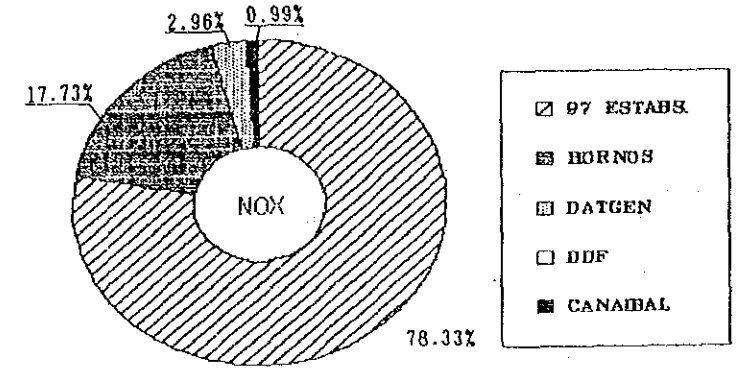
Since the cause of SO_2 emissions is largely combustion of heavy oil, the effect of controlling large factories, that are large consumers of heavy oil, is large.

2) NOx

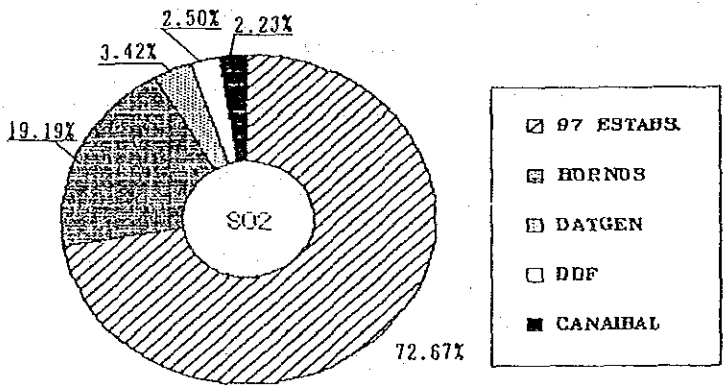
As regards NOx emissions, the contribution of heavy oil and that of natural gas are considered to be at similar levels. Improvement of combustion equipment and combustion method are required for control of NOx emissions in addition to substitution of better quality fuels for the current heavy oil.

3) PM

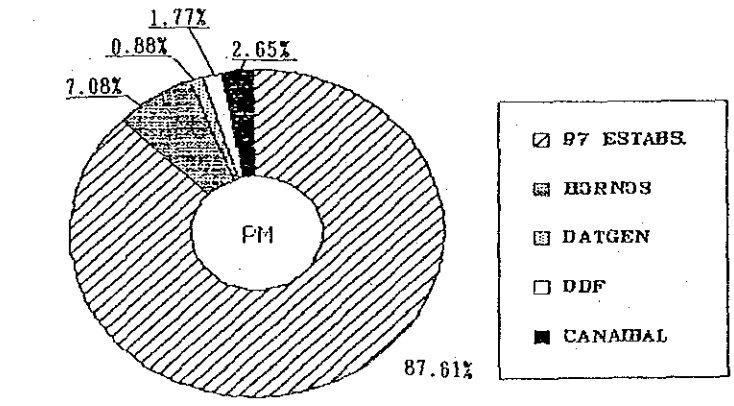
As regards PM emissions, a considerable amount is originating from processing raw materials in asphalt and cement plants regardless of kind of fuel. Therefore, control of fuel combustion alone is not sufficient to reduce PM emissions.



NOX EMISSION



SOX EMISSION



(DDF:SERVICE & COMERCIAL SECTOR IN DF
CANAIBAL:PUBLIC BATH)

PM EMISSION

Figure 3.2.3 Pollutant Emissions from Stationary Sources in AMCM

3.3 Distribution of Pollutant Emissions by Scale of Sources

As shown in Figure 3.3.1, the major pollutant sources are predominantly those selected for the detailed on-site survey. Most of the top 10 factories belong to this group, and the total emission magnitudes of these 10 factories are 60% for NOx and SO_2 and 75% for PM of the total emissions in the AMCM.

The top ten ranking factories in the emissions of NOx, SO_2 and PM are shown in Table 3.3.1, with thermal power generation, cement, glass and paper products industries predominating.

Table 3.3.1 Top 10 Factories in Pollutant Emission

Order	NOx	SO_2	PM
1	Thermoelectric Power (A)	Cement	Asphalt
2	Cement	Thermoelectric Power (A)	Thermoelectric Power (A)
3	Glass Sheet	Paper	Metal Products
4	Thermoelectric Power (B)	Thermoelectric Power (B)	Cement
5	Glass Bottle	Petrochemical (B)	Paper
6	Glass (C)	Alcoholic Drinks	Glass Sheet
7	Petroleum Refinery	Chemical Products	Glass Bottle
8	Paper	Petroleum Refinery	Thermoelectric Power (B)
9	Glass (B)	Paper Products	Glass (A)
10	Chemical Products	Glass (A)	Alcoholic Drinks

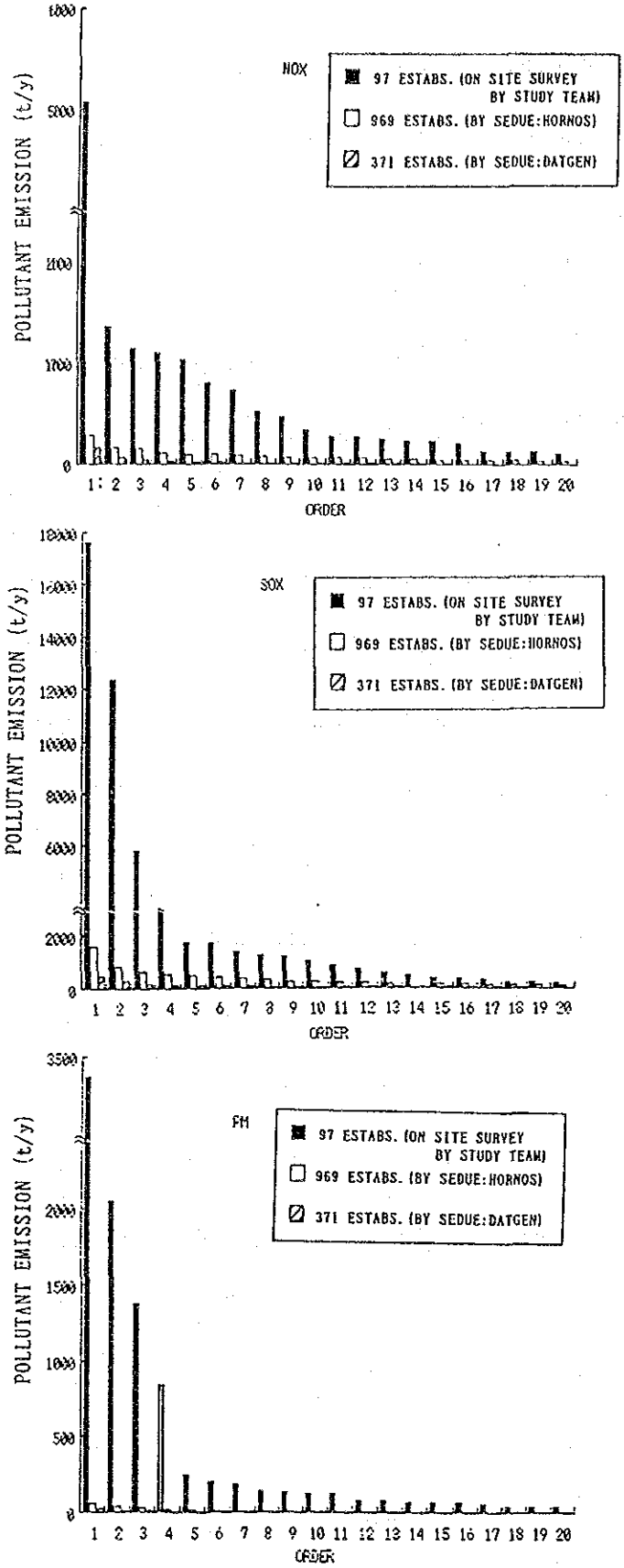


Figure 3.3.1 Pollutant Emission by Top 20 Factories

3.4 Amount of Pollutant Emission by Types of Combustion Facility

Among all the establishments surveyed in this Study, the upper ranking 1,066 establishments have approximately 3,600 combustion facilities, of which boilers of various sizes account for approximately 40%. Assuming at least one combustion facility being possessed by each of the rest of the establishments, there are at least 6,644 additional facilities, making the total number of combustion facilities considered in this Study over 10,000.

The pollutant emission volumes by types of combustion facilities in the 97 establishments surveyed through the detailed on-site questionnaire are shown in Figure 3.4.1. According to the Figure, large boilers are generally large pollution sources. With regard to PM, however, the aggregate dryers of an asphalt plant are by far the largest sources.

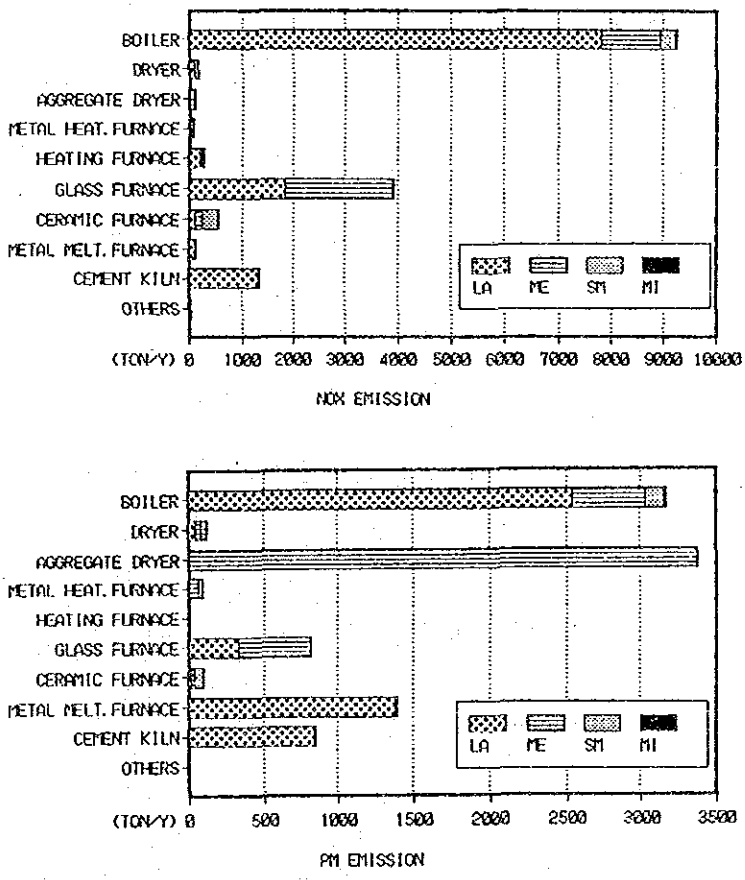


Figure 3.4.1 Pollutant Emission by Types and Scales of Combustion Facility in the 97 Establishments for the Detailed On-site Questionnaire

3.5 Geographical Distribution

Figure 3.5.1 shows the distribution of the on-site-surveyed 97 establishments and the SEDUE-covered 1,340 establishments in the Study area expressed with the density of establishments in the 2 km square areas. These establishments, which are considered to include most of major factories in AMCM, are concentrated in the northern part of DF and its extension in the State of Mexico.

This distribution is nearly in correspondence with the urbanization distribution shown in Figure 3.5.2.

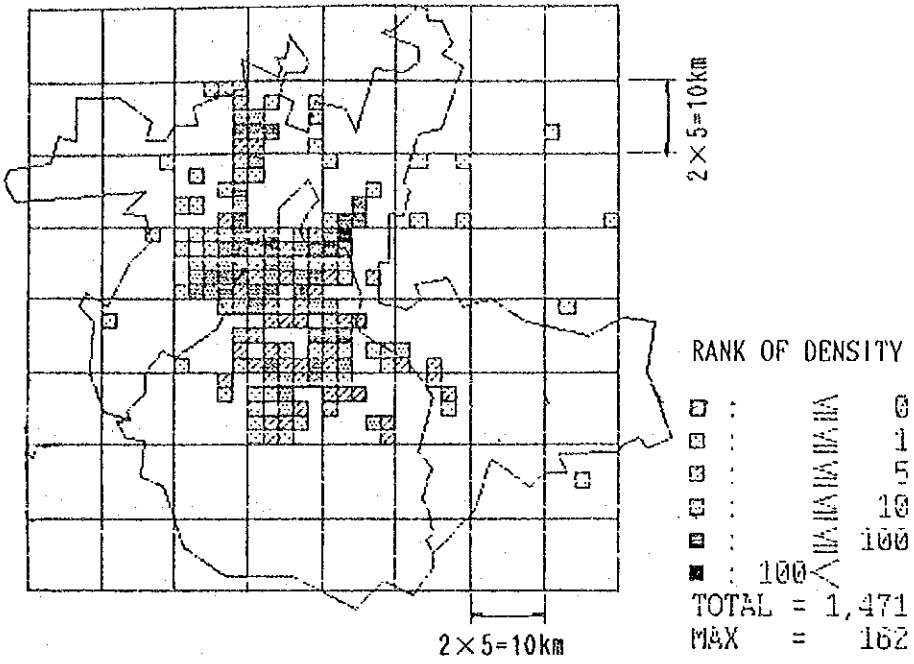
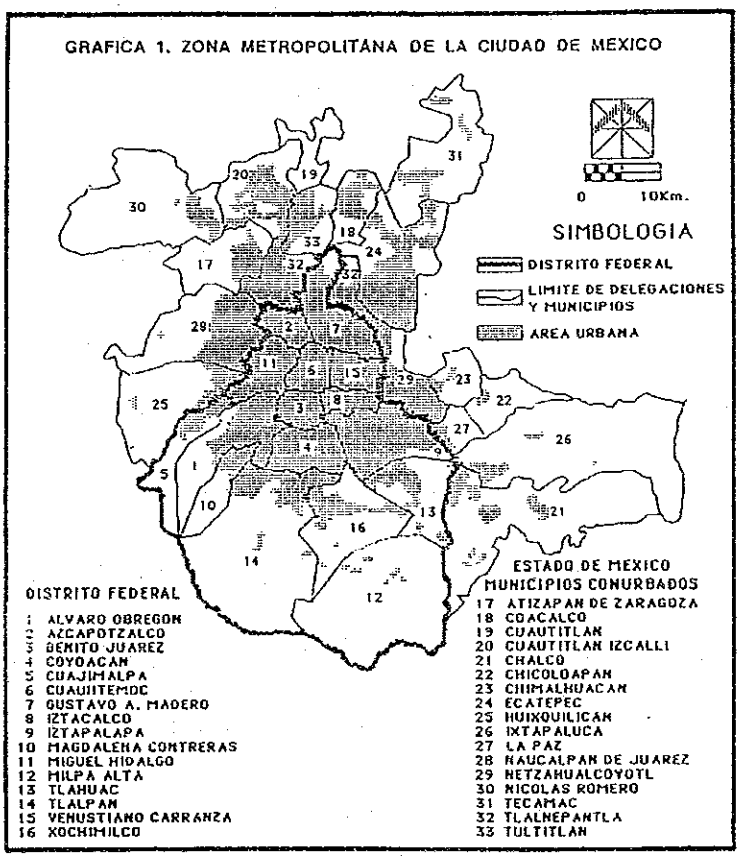


Figure 3.5.1 Factory Density Distribution in AMCM



Source: Integrated Program Against Atmospheric Pollution in the Mexico City Metropolitan Zone - A Common Agreement, Oct. 1990

Figure 3.5.2 Distribution of Urbanized Zones in AMCM

CHAPTER 4 BASIC DISCUSSIONS ON AIR POLLUTION CONTROL OF STATIONARY SOURCES

4.1 Outline of Source Control Measures

Table 4.1.1 summarizes currently available emission control technologies for sulfur oxides (SOx), nitrogen oxides (NOx), and smoke and soot.

Emphasis in the pollution control study will be placed on the control of NOx and particulate matter in this Study. Appropriate control technologies should be selected for each source based on the understanding of actual status of the source.

Table 4.1.1 Emission Control Technologies for SOx, NOx, and Particulate Matter (PM)

Category	Technology	Reduction Effect			Applicable Facility Scale
		SOx	NOx	PM	
Improvement of fuel	Reduction of S content of fuel (reduction of N content is difficult)	Large	Some	Some	All
Change of fuel	From heavy oil to natural gas or diesel	Large	Effective	Effective	All
Improvement of combustion control (energy saving)	1. Improvement of heat recovery 2. Optimization of air flow 3. Low air-ratio combustion	Reduction of emissions resulting from reduction of fuel use (indiredt effect)			All
Improvement of combustion method	1. Improvement of operational condition				
	• Low air-ratio combustion	-	Effective	Increase	All
	• Reduction of combustion chamber loading	-	Effective	Decrease	All
	• Reduction of air preheating temperature	-	Effective	Tends to increase	Large
	2. Improvement of equipment				
	• Low-NOx burner	-	20-45%	Increase with some burners	Small to medium
	• Two-stage combustion	-	20-45%	Slight tendency to increase	Lage
	• Off-stoichiometric combustion	-	20-45%	Slight tendency to increase	Facilities with 2 or more burners
	• Exhaust gas recirculation	-	20-45%	Slight tendency to decrease	Large
	• Steam/water injection	-	20-45%	Slight tendency to decrease	All
	• In-furnace denitration combustion (OFA method)	-	30-40%	Slight increase	Large
	• In-furnace denitration combustion (MACT method)	-	50%	Slight increase	Large
	3. Emulsion Combustion	Effective by addition of alkali metals	30-50%	20 - 40%	All
Exhaust gas treatment	1. Dust removal				
	• Electric precipitator	-	-	90% or more	Lage
	• Bag filter	-	-	90% or more	All
	• Scrubber	90% by use of absorbent	-	90% or more	All
	• Centrifuge	-	-	90% or more	Small to medium
	• Inertial force				
	Louver type	-	-	70-80% for <15μm	All
	Multi-baffle type	-	-	70-80% for <5μm	All
	• Gravity	-	-	50% for <50μm	All
	2. Desulfurization	90% or more	-	50% or more	All
	3. Denitration	-	90% or more	-	Large
	4. Total treatment of exhaust gas	90% or more	90% or more	90% or more	Large
Others	1. Plant relocation	Effects at original site are large. But high cost and availability of a suitable new location are required.			All
	2. District heat supply	Energy-saving effect due to concentrating scattered sources. But control measures are required at the heat supply source.			Small to medium
	3. Higher smokestacks	Ground-level concentration is reduced. But the total emission is unchanged.			All

4.2 Assumptions and Approach to Stationary Source Control Planning

4.2.1 Prospect of Demand and Supply of Fuels

(1) Prospect of Energy Demand by Stationary Pollution Sources

As has been described in Chapter 2, Section 2.5, AMCM is restricting expansion of industrial activity. Especially for activity types requiring much energy and water consumption and discharging much pollutants, strict restrictive measures including relocation and shutdown of plants are adopted.

As an notable example of such measures, the shutdown of the refinery process in the 18 de Marzo Refinery, which was the only oil refinery plant in AMCM, can be named.

On the other hand, the population of the metropolitan area, approximately 15 million at present, has been increasing, but with the decreasing rate of growth since 1980, and is expected to reach around 18 million in 2010.

With this population growth, the service and commercial industry will continue expanding, and will provide in turn increasing employment. However, since the stationary pollution sources in the service and commercial industry consume far less fuel than those in the manufacturing industry, the overall fuel demand in the metropolitan area is not considered to be influenced by the increasing number of these facilities.

Considering the above mentioned factors together, the fuel consumption in the future by the stationary pollution sources in AMCM is assumed to be unchanged from the present level.

(2) Characteristics and Prices of Major Fuels

1) Currently Supplied Fuels

The most desirable fuel from the air pollution control viewpoint is one that emits least quantity of pollutants per unit heat output. Table 4.2.1 shows the pollutant emissions per unit heat output of the major fuels currently in supply.

Table 4.2.1 Emission Factors for Fuels per Unit Heat Output

		Heavy oil	Diesel	Natural gas
Emission factor ($kg/10^6$ kcal)	NOx	0.74	0.20	0.33
	SO_2	7.00	2.12	0.001
	PM	0.28	0.20	0.02
Calorific value (10^6 kcal)		$9.77/m^3$	$8.80/m^3$	$8.52/10^3m^3$

As shown in the Table, natural gas is the lowest in both SO_2 and PM emissions followed by diesel. Heavy oil is the highest.

Table 4.2.2 shows a comparison of prices of the major three fuels in terms of calorific value.

Table 4.2.2 Price of Major Fuels per Unit Heat Value

		H. oil	Diesel	N. gas
Calorific value (10^3 kcal)		9.77/l	8.80/l	$8.52/m^3$
Price	(Pesos)	228/l	605/l	$245/m^3$
	(Pesos/10^3 kcal)	23.3	68.8	28.8

In price per unit heat, heavy oil is the lowest followed by natural gas. The price of diesel is about 3 times that of heavy oil, and 2.4 times that of natural gas.

2) Desulfurized Hevy Oil (DHO) and Desulfurized and Emulsified Heavy Oil (DEHO)

It is expected that desulfurized heavy oil (DHO) with the S content at 0.8% will be supplied from the year 1995 as a measure to reduce SO_2 emissions. As a measure to reduce NOx and PM emissions, emulsification of this DHO can be considered. Effects of DHO and the emulsified DHO (DEHO) in pollutant reduction as compared with the current heavy oil are estimated as shown in Table 4.2.3. Note that the actual effects of DEHO need to be confirmed by thorough demonstration tests.

Table 4.2.3 Pollutant Reduction Effects of Improved Heavy Oil

	NOx (%)	SO_2 (%)	PM (%)
Current heavy oil	0	0	0
DHO	10	73	20
DEHO	30	73	40

Note: DHO = desulfurized heavy oil
DEHO = desulfurized and emulsified heavy oil

Since the price of DHO has not been decided yet, it is set to 320 pesos per liter in this Study by adding the estimated desulfurization cost of US$ 5.00/barrel to the price of the current heavy oil. And the price of further improved DEHO is expected to be 390 pesos per liter. When changes in the calorific value by these processes are taken into consideration, their prices per unit heat are 33 pesos/1,000 kcal and 40 pesos/1,000 kcal, respectively. These prices are substantially higher than that of the current heavy oil, but still lower than that of diesel. The above prices will be used in this Study in order to clarify the costs of air pollution control measures. However, since the prices of individual fuels are determined through the nationl energy policy, the prices shown above may be changed, and therefore, fuel expenses in individual sources estimated in this Study may be changed.

(3) Fuel Supply by Kinds

Supply of the desulfurized heavy oil of the S content at 0.8% is expected in AMCM from 1995 to meet the demand sufficiently.

PEMEX is planning to increase natural gas supply to the metropolitan area up to 1994. When the production of hydro-desulfurized heavy oil will have started, the natural gas supply will be reduced temporarily.

The annual consumption of diesel by the stationary pollution sources in the metropolitan area at present is estimated to be around 500,000 m^3, which is only one 5000th of the total consumption of diesel by the stationary users in the nation, and one 2000th of the national total for the final consumption industry sector. This means that if the factories in the metropolitan area will need it, the supply can be increased without much difficulty, on middle and long term basis.

4.2.2 Approach to Air Pollution Control Planning of Stationary Sources

(1) Assumptions and Premises

The study of stationary source control measures for the metropolitan area will be made under the following assumptions or premises:

1) Supply of desulfurized heavy oil (S : 0.8%) will be made by sufficient amount for demand in the metropolitan area from around 1995.

2) The energy consumption by the stationary air pollution sources in the future of 2000 - 2010 will not increase from the present level.

3) The amounts of emission of SO_2, NOx and smoke and soot from large scale emission sources are to be reduced by certain degrees from the level of 1990.

(2) NOx Control Measures

To control NOx, the most effective method is, as with other pollutants, to suppress its generation. To be practical for the sources in AMCM, the study priority will be given to the improvement of combustion method such as flue gas recirculation, two-stage combustion, low-NOx burners, emulsion combustion, and in-furnace denitration combustion (OFA method, MACT method, etc.). With respect to the emulsion combustion, its principles have been technologically confirmed, but there are not many cases of practical application in Japan. And since its NOx reduction effect varies considerably depending on the types of fuels and burners, a commercial scale test with Mexican heavy oil should be conducted to confirm its NOx reduction effect and cost effectiveness as a prerequisite to practial application.

(3) SOx Control Measures

When the supply of the desulfurized heavy oil as mentioned above will have started, the SO_2 emissions from the stationary sources in the metropolitan area will be reduced to around 30% of the present level. But for some sources such as the power plants, additional SO_2 control measures will be needed. The following are available at present: 1) change to better quality fuel, and 2) flue gas desulfurization.

In the present Study, flue-gas desulfurization will be excluded because of huge costs, and fuel improvement through mixing the desulfurized heavy oil with other quality fuels will be mainly taken into consideration.

(4) Particulate Matter Control Measures

Since particulate matter can be reduced basically through generation control technologies such as fuel improvement and combustion method improvement, priority will be placed on generation control.

For controlling dust generated during the process of drying raw materials and products, introduction of bag filters or electrostatic precipitators of high efficiency will be basically taken into consideration.

(5) Process of Changing to Better Quality Fuel

The use of better quality fuels in place of the current fuel is effective in reducing all three types of pollutants; SO_2, NOx and particulate matter. For the facilities currently using only heavy oil, the following fuel improvement processes are considered to be practical:

1) Mixed burning of heavy oil and diesel or natural gas until the start of supply of the desulfurized heavy oil.

2) The above heavy oil is replaced by the desulfurized heavy oil as its supply starts.

3) When further improvement is required, either diesel only is used or the desulfurized heavy oil and natural gas are used for mixed combustion.

The concrete procedure should be determined case by case in consideration of the peculiar conditions of the individual facilities.

CHAPTER 5 DIAGNOSIS OF THE SELECTED STATIONARY SOURCES AND STUDY OF POLLUTION CONTROL MEASURES

5.1 Selected Stationary Sources and Facilities

A total of 25 establishments were selected as representative stationary sources of air pollution in AMCM.

The selection was made under the following considerations.

1) While establishments considered as large scale pollution source should be preferentially selected, those representative of small to medium scale sources should be also included.

2) There should be a variety in the kind of pollutant emitting facilities. Industrial furnaces of the kinds representative of AMCM should be included as well as various types and scales of boilers.

3) Types of industry should be representative of AMCM.

Under such considerations, about 100 establishments were selected through consultation with SEDUE. They were invited to an explanation seminar and visited by the Study Team and the Mexican counterpart for the detailed on-site questionnaire. Basic information as stationary pollution source was thus collected from 97 establishments actually visited.

Through the careful review of the above information on the 97 establishments, the 25 establishments were selected for the diagnostic survey. They are shown in Table 5.1 with their facilities subjected to diagnosis. A total of 54 facilities were diagnosed.

Table 5.1 Facilities Investigated by Diagnostic Survey

No.	Identity of Establishment	Visit No.	Type of Industry	Industrial boiler				Industrial furnace						
				Large capacity	Medium capacity	Small capacity	HTM* boiler	Oil heating	Dryer	Aggregate dryer	Cement kiln	Glass melting	Metal heating	Metal melting
1	Thermoelectric Power Plant (A)	69	Electric power	4										
2	Thermoelectric Power Plant (B)	70		2										
3	Petroleum Refinery	57	Petroleum refinery	1	4			9						
4	Chemical Products Factory (A)	1	Chemical products		1	1	2		2					
5	Chemical Products Factory (B)	62				1		1						
6	Chemical Products Factory (C)	72				2								
7	Chemical Products Factory (D)	24				1								
8	Chemical Products Factory (E)	67				1								
9	Petrochemical Products Factory (A)	16	Petrochemical products		2									
10	Petrochemical Products Factory (B)	8			2									
11	Petrochemical Products Factory (C)	87				1								
12	Asphalt Plant	11	Petroleum products							3				
13	Cement Factory	41	Non-metal mineral products							1	1			
14	Glass Factory (A)	68										1		
15	Glass Factory (B)	31										1		
16	Glass Factory (C)	23										2		
17	Rubber Products Factory	14	Rubber and plastic		1									
18	Paper Factory	30	Paper and its products		2									
19	Paper Products Factory (A)	34				1								
20	Paper Products Factory (B)	76				1								
21	Metal Products Factory (A)	55	Metal products										1	
22	Metal Products Factory (B)	19												1
23	Food Products Factory	65	Food		1									
24	Alcoholic Drinks Factory	47	Drinks	1										
25	Public Bathhouse	52	Bathhouse			1								
	Total Number			8	13	10	2	10	2	4	1	4	1	1

Note : HTM boiler = Heat transfer medium boiler

5.2 Results of the Diagnostic Survey

Major items investigated in the diagnosis of each selected facility are as follows:

1) Outlines of the facility

2) Kind of fuel, its sulfur content, and consumption amount

3) Operational conditions in combustion: fuel pressure, combustion temperature, fuel-air ratio, etc.

4) Exhaust gas flowrate and concentration of pollutants including NOx, PM, CO, CO_2 and O_2.

An outline of these basic data obtained from each facility at each establishment is given in Table 5.2.

Table 5.2 Outline of Results of Flue Gas Measurement in the Diagnostic Survey

No.	Name of Establishment	Visit No.	Name of Facility	Date		Time	Recuperator O2 (%)	Recuperator Ts (℃)	Stack Gas O2 (%)	Stack Gas Ts (℃)	Stack Gas NOx (ppm)	Stack Gas CO2 (%)	Stack Gas CO (%)	Stack Gas PM (mg/m3)	Stack Gas v (m/s)	Stack Gas Diam. (m)	Stack Gas Area (m2)	Stack Gas Air ratio	Stack Gas H2O (%)	Stack Gas Qdry (m3N/hr)	Fuel Consumption Gas (m3/hr)	Fuel Consumption Oil (l/hr)	Fuel Consumption Diesel (l/hr)	Sulfur in Oil w/w(%)	NOx (O2 0%) (ppm)	NOx (O2 5%) (ppm)	Emission NOx (kg/hr)	Emission SO2 (kg/hr)	Emission PM (kg/hr)
1	THERMOELECTRIC POWER PLANT (A)	69-1	No.1 Boiler	Sep. 4		15:00-16:00	1.3	-	3.6	159	170	8.3	<0.05	45	23.8	3.800	11.341	1.21	13	414,000	30,200	1,600	-	3.52	205	156	140	110	19
		69-2	No.2 Boiler	Sep. 4	1	12:30-13:30	3.8	412	4.5	177	86	8.4	<0.05	4.7	24.0	3.900	11.946	1.27	12	427,000	32,200	870	-	3.52	109	83	75	60	2.0
				Sep. 13	2	13:30-14:30	-	369	5.3	152	101	9.8	<0.05	470	26.0	3.900	11.946	1.34	10	501,000	18,400	20,500	-	3.52	135	103	100	1,400	240
		69-3	No.3 Boiler	Nov. 14		13:30-14:30	6.3	380	8.4	132	113	7.3	<0.05	-	31.5	3.900	11.946	1.67	9	642,000	24,900	15,000	-	3.57	188	143	150	1,100	-
		69-4	No.4 Boiler	Sep. 13		14:30-15:30	1.6	-	7.0	182	149	6.6	0.10	120	14.8	Rectan. 37.975		1.50	11	837,000	55,500	6,000	-	3.52	224	170	260	420	100
2	THERMOELECTRIC POWER PLANT (B)	70-1	No.1 Boiler	Sep. 6	1	13:00-14:00	2.3	-	7.1	170	233	7.0	<0.05	45	19.9	2.320	4.227	1.51	11	128,000	8,300	2,600	-	3.43	352	268	61	180	5.8
					2	15:30-16:30	3.4	-	7.7	169	214	7.4	-	270	20.6	2.320	4.227	1.58	11	134,000	4,600	6,500	-	3.43	338	257	59	440	36
		70-2	No.2 Boiler	Sep. 6		13:30-14:30	1.3	367	5.1	185	168	8.6	<0.05	25	28.8	2.260	4.011	1.32	12	169,000	10,600	2,400	-	3.43	222	169	58	160	4.2
3	PETROLEUM REFINERY	57-5	AA-F1 & F2 Heating furnace	Sep. 25		12:30-13:30	-	-	5.5	555	89	8.3	<0.05	< 0.3	8.0	3.430	9.240	1.35	11	60,500	‡ 6,100	-	-	-	121	92	11	-	< 0.018
		57-6	AA-F3 Heating furnace	Sep. 10		15:00-16:00	-	-	6.8	400	54	7.8	<0.05	0.7	1.9	2.134	3.577	1.48	10	6,900	‡ 540	-	-	-	80	61	0.77	-	0.0048
		57-4	RV-H1 Heating furnace	Sep. 10		13:00-14:00	-	-	6.9	384	52	6.3	<0.05	1.3	5.9	1.980	3.079	1.49	12	18,500	‡ 1,500	-	-	-	77	59	2.0	-	0.024
		57-10	AW-H1 Heating furnace	Sep. 11		13:00-14:00	-	-	2.2	610	71	10.2	<0.05	0.9	4.2	2.134	3.577	1.12	13	11,200	‡ 540	-	-	-	79	60	1.6	-	0.010
		57-12	RE-H10 Heating furnace	Sep. 21		15:00-16:00	-	-	13.0	420	27	3.7	<0.05	< 0.2	3.9	3.048	7.297	2.63	7	29,000	‡ 1,300	-	-	-	71	54	1.6	-	< 0.0058
		57-13	AR-H1 & AU-H1 Heating furnace	Sep. 18		13:00-14:00	-	-	9.6	375	30	6.6	<0.05	1.4	4.5	2.841	6.339	1.84	7	31,200	‡ 2,300	-	-	-	55	42	1.9	-	0.044
		57-16	AQ-H1 Heating furnace	Sep. 14		12:30-13:30	-	-	10.9	418	50	5.1	<0.05	< 0.5	7.7	1.450	1.651	2.08	8	12,900	‡ 700	-	-	-	104	79	1.3	-	< 0.0065
		57-1-1	G1 Boiler	Sep. 27	1	12:30-13:30	4.1	298	5.1	232	142	8.4	<0.05	90	13.5	2.134	3.577	1.32	12	63,800	~ 4,900	~ 570	-	3.17	188	143	19	36	5.7
							4.1	298	5.1	232	142	8.4	<0.05	90	13.5	2.134	3.577	1.32	12	63,800	‡ 2,800	‡ 400	-	3.17	188	143	19	25	-
					2	14:15-14:45	4.0	306	5.1	237	135	8.6	<0.05	16	13.0	2.134	3.577	1.32	11	61,500	‡ 3,200	-	-	-	178	136	17	-	0.98
		57-1-2	G2 Boiler	Sep. 11		14:00-15:00	4.1	380	4.6	217	112	8.5	<0.05	6.0	6.1	2.134	3.577	1.28	13	29,500	‡ 2,600	‡ 1,500	-	3.17	143	109	6.8	94	0.18
		57-1-3	G3 Boiler	Sep. 17		12:00-13:00	9.3	326	10.5	242	49	5.7	<0.05	7.1	8.2	2.134	3.577	2.00	8	39,800	‡ 1,800	~ 380	-	3.17	98	75	4.0	24	0.28
		57-2	G5 Boiler	Sep. 26		12:30-13:30	3.0	420	5.5	220	120	8.6	<0.05	51	7.8	3.275	8.424	1.35	11	89,900	‡ 8,800	~ 1,100	-	3.17	163	124	22	69	4.6
		57-3	CP Boiler	Sep. 19		13:30-14:30	-	-	1.3	282	105	11.5	<0.05	< 0.2	7.8	2.134	3.577	1.07	13	33,100	‡ 2,200	~ 470	-	3.17	112	85	7.1	29	< 0.0066
4	CHEMICAL PRODUCTS FACTORY (A)	1-5	No.D Boiler	Oct. 8		16:30-17:00	-	-	0.9	267	30	10.9	0.70	1.5	8.3	0.763	0.457	1.04	14	4,600	450	-	-	-	31	24	0.28	-	0.0069
		1-1	No.E Boiler	Oct. 8		13:00-14:00	-	-	4.1	253	66	9.3	<0.05	0.9	7.6	1.266	1.259	1.24	11	12,300	1,000	-	-	-	82	62	1.7	-	0.011
		1-6	Heat medium boiler 100	Oct. 9		14:00-15:00	-	-	4.9	198	68	7.3	<0.05	< 0.4	10.2	0.350	0.096	1.30	13	1,400	180	-	-	-	89	68	0.20	-	< 0.0006
		1-8	Heat medium boiler 300	Oct. 9		11:30-12:30	-	-	7.8	170	92	7.1	<0.05	< 0.4	9.0	0.580	0.264	1.59	9	3,700	300	-	-	-	146	112	0.70	-	< 0.0015
		1-11	No.1 Dryer for detergent	Oct. 9		13:00-14:00	-	-	18.6	116	15	1.3	<0.05	27	24.5	1.240	1.208	8.75	12	50,800	300	-	-	-	131	100	1.6	-	1.4
		1-12	No.2 Dryer for detergent	Oct. 8		13:00-14:00	-	-	18.8	82	12	0.8	<0.05	43	15.8	1.680	2.217	9.55	15	63,800	360	-	-	-	115	87	1.6	-	2.7
5	CHEMICAL PRODUCTS FACTORY (B)	62-1	No.1 Boiler	Oct. 29	1	12:00-13:00	-	-	9.8	185	185	7.5	<0.05	-	6.0	0.400	0.126	1.88	6	1,200	-	25	-	2.81	347	264	0.46	1.4	-
					2	15:00-15:30	-	-	4.2	215	265	11.5	<0.05	420	12.0	0.400	0.126	1.25	8	2,100	-	120	-	2.81	331	252	1.1	6.6	0.88
		62-2	Oil heating furnace	Oct. 30		12:30-13:30	-	-	10.3	370	23	7.6	<0.05	33	5.5	0.150	0.018	1.96	5	110	-	-	8	1.02	45	34	0.01	0.13	0.0036
6	CHEMICAL PRODUCTS FACTORY (C)	72-1	No.1 Boiler	Nov. 12		14:20-15:10	-	-	10.8	164	42	5.3	<0.05	7.5	3.0	0.360	0.102	2.06	8	490	110	-	-	-	86	66	0.04	-	0.0037
		72-2	NO.2 Boiler	Nov. 12		15:30-16:00	-	-	7.1	154	44	7.2	<0.05	< 0.9	1.7	0.350	0.096	1.51	10	260	100	-	-	-	66	51	0.02	-	< 0.0002
7	CHEMICAL PRODUCTS FACTORY (D)	24-1	No.4 Boiler	Oct. 1	1	13:00-14:00	-	-	1.8	280	50	9.8	0.15	< 0.2	13.0	0.635	0.317	1.09	14	4,900	530	-	-	-	55	42	0.50	-	< 0.0010
					2	15:20-15:30	-	-	2.8	302	59	9.9	<0.05	-	18.0	0.635	0.317	1.15	12	6,700	700	-	-	-	68	52	0.81	-	-
8	CHEMICAL PRODUCTS FACTORY (E)	67-1	No.1 Boiler	Nov. 6	1	12:30-13:30	-	-	7.0	295	147	9.2	<0.05	51	6.9	0.930	0.679	1.50	10	5,700	-	170	-	3.02	221	168	1.7	10	0.29
					2	13:30-14:30	-	-	11.4	285	100	6.3	<0.05	-	7.4	0.930	0.679	2.19	7	6,300	-	540	-	3.02	219	167	1.3	32	-
9	PETROCHEMICAL PRODUCTS FACTORY (A)	16-3	No.3 Boiler	Sep. 20	1	11:20-12:20	3.9	345	6.9	190	283	10.0	<0.05	5.8	8.7	1.520	1.815	1.49	8	23,800	-	1,800	-	2.97	421	321	14	110	1.4
					2	12:50-13:50	3.3	341	8.8	210	295	9.6	<0.05	78	9.3	1.520	1.815	1.72	5	25,300	-	2,100	-	2.97	508	387	15	120	2.0
		16-4	No.4 Boiler	Sep. 21	1	14:00-15:00	5.5	473	7.4	270	165	6.7	<0.05	< 0.1	12.5	1.670	2.190	1.54	10	34,500	3,200	-	-	-	255	194	12	-	< 0.0035
					2	15:30-16:10	2.6	-	4.6	252	192	8.0	<0.05	-	10.2	1.670	2.190	1.28	13	28,200	3,200	-	-	-	246	187	11	-	-
10	PETROCHEMICAL PRODUCTS FACTORY (B)	8-2	NO.2 Boiler	Oct. 10		13:00-14:00	2.9	342	5.2	217	247	11.0	<0.05	37	8.6	1.970	3.048	1.33	10	36,600	-	2,200	-	2.91	328	250	19	130	1.4
		8-3	NO.3 Boiler	Oct. 10		12:30-13:30	-	-	5.8	253	319	12.0	<0.05	230	2.6	1.500	1.767	1.38	7	6,100	-	600	-	2.89	441	336	4.0	34	1.4
11	PETROCHEMICAL PRODUCTS FACTORY (C)	87-1	No.1 Boiler	Nov. 16	1	12:30-13:30	-	-	12.8	193	177	5.5	<0.05	190	6.2	0.400	0.126	2.56	4	1,200	-	45	-	2.88	453	345	0.44	2.6	0.23
					2	14:24	-	-	8.3	250	275	8.0	<0.05	-	11.8	0.400	0.126	1.65	7	2,000	-	130	-	2.88	455	346	1.1	7.4	-
12	ASPHALT PLANT	11-1	No.1 Kiln for aggregate	Oct. 5		13:30-14:30	13.8	143	16.7	104	45	2.6	<0.05	1,900	15.0	Rectan.	1.515	4.88	13	39,900	-	-	850	1.05	220	167	3.7	15	76
		11-2	No.2 Kiln for aggregate	Oct. 5		11:30-12:40	12.4	156	16.2	96	65	3.7	0.05	3,000	14.0	1.210	1.150	4.37	17	27,600	-	-	850	1.05	284	217	3.7	15	83
		11-3	No.3 Kiln for aggregate	Oct. 16		13:00-14:00	-	-	16.5	88	45	2.9	<0.05	6,200	33.4	Rectan.	0.901	4.67	14	54,400	-	-	950	1.05	210	160	5.0	17	340
13	CEMENT FACTORY	41-8	No.4 SP Kiln	Sep. 18	1	12:30-13:30	6.5	-	7.5	143	320	22.1	<0.05	430	16.1	2.200	3.801	1.56	11	99,700	-	9,000	-	3.66	498	379	66	-	43
					2	14:20-15:20	8.1	-	8.9	140	315	19.5	<0.05	-	15.2	2.200	3.801	1.74	11	94,300	-	8,000	-	3.66	547	417	61	-	-
		41-10	No.8 Dryer	Sep. 17		14:20-15:20	16.6	-	17.3	95	26	1.5	<0.05	< 0.1	7.6	1.755	2.419	5.68	25	28,500	640	-	-	-	148	112	1.5	-	< 0.0029
14	GLASS FACTORY (A)	68-2	No.B Glass melting furnace	Sep. 28		13:00-14:00	-	-	2.9	810	645	17.4	<0.05	760	3.9	1.720	2.324	1.16	12	11,300	-	1,400	-	2.70	748	570	15	74	8.6
15	GLASS FACTORY (B)	31-2	No.2 Glass melting furnace	Sep. 24		14:00-15:00	0.9	1,400	5.4	843	1195	11.4	<0.05	480	4.3	1.220	1.169	1.35	15	3,900	310	-	-	-	1,609	1,226	9.6	-	1.9
16	GLASS FACTORY (C)	23-1	No.B4 Glass melting furnace	Nov. 13		15:30-16:30	5.8	-	6.6	418	580	10.7	<0.05	390	3.8	3.217	8.128	1.46	14	28,200	2,300	-	-	-	846	644	35	-	11
		23-2	No.B2 Glass melting furnace	Nov. 13		15:30-16:30	2.8	-	6.0	465	690	10.5	<0.05	120	4.2	3.217	8.128	1.40	14	30,300	1,800	-	-	-	966	736	43	-	3.6
17	RUBBER PRODUCTS FACTORY	14-1	Boiler	Sep. 25	1	12:30-13:30	-	-	8.5	280	145	6.8	<0.05	260	14.1	0.690	0.374	1.68	11	6,400	-	430	-	2.99	244	186	1.9	25	1.7
					2	14:30-14:40	-	-	6.2	330	250	10.5	<0.05	190	18.9	0.690	0.374	1.42	9	8,100	-	710	-	2.99	355	270	4.2	42	1.5
18	PAPER FACTORY	30-1	No.1 Boiler	Oct. 4		12:30-13:30	11.0	286	12.5	198	178	8.3	<0.05	-	-	1.960	3.017	2.47	9	-	-	710	-	-	440	335	-	-	-
		30-2	No.1 + No.2 Boiler	Oct. 4		14:00-15:00	10.0	462	11.5	218	148	6.2	<0.05	440	7.8	1.960	3.017	2.21	6	34,400	-	1,700	-	3.01	327	249	10	100	15
19	PAPER PRODUCTS FACTORY (A)	34-1	No.1 Boiler	Sep. 27		12:40-13:40	5.6	385	10.3	255	124	7.4	<0.05	280	5.0	1.650	2.138	1.96	7	14,300	-	820	-	2.95	243	185	3.6	48	4.0
20	PAPER PRODUCTS FACTORY (B)	76-1	No.1 Boiler	Nov. 7	1	11:00-12:00	-	-	6.6	345	184	9.6	<0.05	34	14.3	0.730	0.419	1.46	10	6,700	-	780	-	2.93	268	204	2.5	45	0.23
					2	12:30-13:30	-	-	5.2	345	191	10.8	<0.05	-	13.7	0.730	0.419	1.33	10	6,400	-	780	-	2.93	254	193	2.5	45	-
21	METAL PRODUCTS FACTORY (A)	55-1	Heating furnace for billet	Nov. 5		11:30-12:30	-	-	3.4	925	143	9.3	<0.05	-	17.6	0.610	0.292	1.19	12	2,900	780	-	-	-	171	130	0.85	-	-
22	METAL PRODUCTS FACTORY (B)	19-1	Melting furnace for aluminum	Nov. 8	1	13:30-14:15	-	-	15.7	280	9	2.7	<0.05	570	3.6	0.747	0.438	3.96	4	2,100	72	-	-	-	36	27	0.04	-	1.2
				Nov. 9	2	15:00-16:00	-	-	6.8	890	28	7.3	<0.05	130	17.0	0.470	0.173	1.48	10	1,700	120	-	-	-	41	32	0.10	-	0.22
23	FOOD PRODUCTS FACTORY	65-2	NO.2 Boiler	Oct. 31	1	11:30-12:00	4.6	285	5.4	182	182	10.5	<0.05		4.1	1.677	2.209	1.35	10	13,600	-	2,800	-	2.94	245	187	5.1	160	-
					2	14:00-15:00	4.1	350	4.8	235	205	11.5	<0.05	210	7.9	1.677	2.209	1.30	10	23,500	-	4,500	-	2.94	266	202	10	260	4.9
24	ALCOHOLIC DRINKS FACTORY	47-2	No.2 Boiler	Sep. 26	1	15:00-16:00	2.5	320	4.3	178	242	12.0	<0.05	410	16.9	1.748	2.400	1.26	10	61,600	-	5,400	-	2.96	304	232	31	310	25
					2	16:20-17:20	3.1	320	6.1	175	239	11.3	<0.05	-	16.1	1.748	2.400	1.41	7	61,000	-	4,700	-	2.96	337	257	30	270	-
25	PUBLIC BATHHOUSE	52-1	No.1 Boiler	Nov. 19		12:30-13:30	-	-	10.5	170	125	6.0	0.25	150	4.2	0.550	0.238	2.00	7	1,600	-	100	-	2.94	250	190	0.41	5.8	0.24

Note: Visit No. :Number in order of visiting for on-site questionnaire survey of 97 establishments.
Recuperator:O2 and Ts for recuperator were measured at the inlet.
Qdry :Flue gas quantity at dry base.
‡ :Estimated by the refinery.
~ :Estimated by the Study Team.

5.3 Outlines of the Control Measures

5.3.1 Outlines of Proposed Measures

Equipment-related control measures proposed based on the diagnostic survey are summarized in Table 5.3.1

Table 5.3.1 Equipment Related Control Measures Proposed

Control Measure	Number of establishments (facilities) applied	
Reduction of combustion chamber loading	3	(8)
Burner nozzle renewal	1	(1)
Low-NOx burners	10	(25)
Exhaust gas recirculation	11	(25)
Tow-stage combustion	2	(5)
Off-stoichiometric combustion	3	(6)
In-furnace denitation combustion	2	(8)
Installation of precalciner	1	(2)
Heat insulation of furnace ceiling	3	(8)
Bag filter	2	(4)
Electrostatic precipitator (EP)	4	(10) *
Air preheater	1	(2)
Combustion control instruments	8	(18)
HC reduction measures	1	
Simple repair by owner	2	
Automatic O_2 analyzer	9	
Portable O_2 analyzer	5	
Others	2	

Note: * Excludes 8 boilers in 2 power plants.

For fuel change or improvement in the facilities using heavy oil exclusively, the following 3 cases are considered.

Case A: Mixed burning with diesel or natural gas in the 50:50 ratio:
Until the supply start of desulfurized heavy oil

Case B: Use of desulfurized heavy oil:
After the supply start of desulfurized heavy oil and when its emulsification is not feasible

Case C: Use of desulfurized and emulsified heavy oil:
After the supply start of desulfurized heavy oil and when its emulsification is feasible, except glass plants remaining in Case B

The proposed control measures for each establishments are outlined in Tables 5.3.2 (1) through 5.3.2 (6).

Table 5.3.2 (1) Control Measures for the 25 Establishments (1/6)

#	NAME OF ESTABLISHMENT	NAME OF FACILITIES	FUEL IN USE	CAPACITY (ton/hr)	CONTROL MEASURES		REDUCTION			INVEST.
					IMPROVEMENT OF COMBUSTION EQUIPMENT	FUEL CHANGE OR OTHERS	NOX (%)	SO2 (%)	PM (%)	(1000 US$)
1.	Thermoelectric Power Plant (A)	Water Tube Boiler (No.1) Water Tube Boiler (No.2) Water Tube Boiler (No.3) Water Tube Boiler (No.4)	HO + Gas HO + Gas HO + Gas HO + Gas	476.00 503.50 503.50 900.00	1 Exhaust gas recirculation 2 In-furnace denitration combustion 3 Combustion control using automatic O2 analyzer 4 Supplementation/Improvement of combustion control instruments 5 Installation of telemetric monitoring system 6 Low NOx burner 7 Installation of EP (for case B)	A: 80% Gas+20% HO → no change B: → 50% Gas+50% DHO (under the use of EP) C: → 50% Gas+50% DEHO	30 27 42	0 45 44	0 87 37	10,930 98,680 13,043
2.	Thermoelectric Power Plant (B)	Water Tube Boiler (No.1) Water Tube Boiler (No.2) Water Tube Boiler (No.3) Water Tube Boiler (No.4)	HO + Gas HO + Gas HO + Gas HO + Gas	150.00 150.00 350.00 350.00	1 Exhaust gas recirculation 2 In-furnace denitration combustion 3 Combustion control using automatic O2 analyzer 4 Supplementation/Improvement of combustion control instruments 5 Installation of telemetric monitoring system 6 Low NOx burner	A: 80% Gas+20% HO → no change B: → 80% Gas+20% DHO C: → 80% Gas+20% DEHO	30 37 54	0 79 79	-14 9 46	6,778
3.	Petroleum Refinery	Water Tube Boiler x 2 Packaged Boiler CO Boiler Heating Furnace x 12	HO + Gas HO + Gas HO + Gas		None	The plant has been closed.	100	100	100	-
4.	Chemical Products Factory (A)	Water Tube Boiler x 5 Heat Medium Boiler x 5	Gas		1 Portable O2 analyzer (Low air ratio combustion)	None	0	0	90	1,420
		Dryer (No.1) Dryer (No.2) Dryer (No.3)	Gas	10.00 10.00 60.00	1 Installation of bag filter	None				
5.	Chemical Products Factory (B)	Smoke Tube Boiler	HO	2.60	1 Exhaust gas recirculation 2 Supplimantation/Improvement of combustion control instruments	A: HO → Diesel	25	82	20	41
		Oil Heating Furnace	Diesel		Change of burner nozzle	None				

Note: HO = Current heavy oil, DHO = Desulfurized heavy oil, DEHO = Desulfurized and emulsified heavy oil

Table 5.3.2 (2) Control Measures for the 25 Establishments (2/6)

#	NAME OF ESTABLISHMENT	NAME OF FACILITIES	FUEL IN USE	CAPACITY (ton/hr)	CONTROL MEASURES		REDUCTION			INVEST.
					IMPROVEMENT OF COMBUSTION EQUIPMENT	FUEL CHANGE OR OTHERS	NOX (%)	SO2 (%)	PM (%)	(1000 US$)
6.	Chemical Products Factory (C)	Smoke Tube Boiler Smoke Tube Boiler	Gas Gas	2.35 1.56	1 Portable O2 analyzer (Low air tatio combustion) 2 Installation of HC incinerator 3 Prevention of HC evaporation by cooling	None	0	0	90 (HC)	116
7.	Chemical Products Factory (D)	Water Tube Boiler x 2 Smoke Tube Boiler x 2 (Spare)	Gas Gas	7.70 3.80	1 Portable O2 analyzer (Low air ratio combustion)	None	0	0	0	2
8.	Chemical Products Factory (E)	Water Tube Boiler Water Tube Boiler	HO HO	3.80 2.60	1 Low NOx burner 2 Combustion control using automatic O2 analyzer	A: HO → 50% HO +50% Diesel B: → DHO C: → DEHO	45 18 58	43 68 68	14 14 32	145
		Heat Medium Boiler	HO			None				
9.	Petrochemical Products Factory (A)	Water Tube Boiler Water Tube Boiler	Gas Gas	14.00 41.00		None				1,058
		Water Tube Boiler	HO	28.00	1 Low NOx burner 2 Exhaust gas recirculation 3 Off-stoichiometric combustion 4 Combustion control using automatic O2 analyzer 5 Installation of telemetric monitoring system	A: HO → 50% HO +50% Gas B: → DHO C: → DEHO	38 15 43	50 73 73	50 20 40	

Note: HO = Current heavy oil, DHO = Desulfurized heavy oil, DEHO = Desulfurized and emulsified heavy oil

Table 5.3.2 (3) Control Measures for the 25 Establishments (3/6)

#	NAME OF ESTABLISHMENT	NAME OF FACILITIES	FUEL IN USE	CAPACITY (ton/hr)	CONTROL MEASURES		REDUCTION			INVEST.
					IMPROVEMENT OF COMBUSTION EQUIPMENT	FUEL CHANGE OR OTHERS	NOX (%)	SO2 (%)	PM (%)	(1000 US$)
10.	Petrochemical Products Factory (B)	Water Tube Boiler Water Tube Boiler	HO HO	40.00 40.00	1 Low NOx burner 2 Exhaust gas recirculation 3 Combustion control using automatic O2 analyzer 4 Installation of telemetric monitoring system 5 Repair of air preheater	A: HO → 50% HO +50% Diesel B: → DHO C: → DEHO	51 36 60	41 72 73	20 20 40	1,350
		Smoke Tube Boiler	HO	13.00	1 Low NOx burner 2 Exhaust gas recirculation 3 Two-stage combustion 4 Combustion control using automatic O2 analyzer 5 Installation of telemetric monitoring system					
11.	Petrochemical Products Factory (C)	Smoke Tube Boiler	HO	2.40	1 Supplementation/Improvement of combustion control instruments 2 Exhaust air recirculation	A: HO → 50% HO +50% Diesel B: → DHO C: → DEHO	44 20 55	41 73 73	20 20 40	37
12.	Asphalt Plant	Rotary Kiln x 3	Diesel	250.00	None	Plant relocation	100	100	100	-
13.	Cement Factory	Rotary Kiln x 2	HO	96.00	1 Installation of electrostatic precipitator 2 Installation of telemetric monitoring system 3 Installation of pre-calciner	A: HO → 50% HO +50% Gas B: → 50% DHO+50% Gas	41 41	69 86	90 90	45,082
		Rotary Kiln Heat Medium Boiler x 2 Hot Water Boiler	HO HO HO	25.00 1.30 1.30	None					
		Drying Furnace x 2 Drying Furnace	Gas Gas	180.00 45.00	None	None				

Note: HO = Current heavy oil, DHO = Desulfurized heavy oil, DEHO = Desulfurized and emulsified heavy oil

Table 5.3.2 (4) Control Measures for the 25 Establishments (4/6)

#	NAME OF ESTABLISHMENT	NAME OF FACILITIES	FUEL IN USE	CAPACITY (ton/hr)	CONTROL MEASURES		REDUCTION			INVEST.
					IMPROVEMENT OF COMBUSTION EQUIPMENT	FUEL CHANGE OR OTHERS	NOX (%)	SO2 (%)	PM (%)	(1000 US$)
14.	Glass Factory (A)	Glass Melting Furnace Tank Oven x 2	HO	12.00	1 Reduction of combustion chamber loading 2 Installation of electrostatic precipitator 3 Installation of telemetric monitoring system 4 Strengthening of heat insulation of furnace/boiler ceiling 5 Combustion control using automatic O2 analyzer	A: HO → 50% HO +50% Diesel B: → DHO Other: Reduction of nitrates in raw material	44 20	41 73	95 95	3,009
		Glass Annealing Furnace	L.P.G		None	None				
15.	Glass Factory (B)	Melting Furnace Melting Furnace Melting Furnace	Gas Gas Gas	1.30 0.90 0.70	1 Off-stoichiometric combustion 2 Reduction of combustion chamber loading 3 Strengthening of heat insulation of furnace/boiler ceiling 4 Installation of electrostatic precipitator	Other: Reduction of nitrates in raw material	50	0	95	2,522
		Water Tube Boiler x 2 (Alternate Use by every 6 months)	Gas	3.10	None	None				
16.	Glass Factory (C)	Glass Melting Furnace Tank Oven Glass Melting Furnace Tank Oven x 2	Gas Gas	16.70 8.30	1 Off-stoichiometric combustion 2 Combustion control using automatic O2 analyzer 3 Installation of electrostatic precipitator 4 Reduction of combustion chamber loading 5 Installation of telemetric monitoring system 6 Strengthening of heat insulation of furnace/boiler ceiling	Other: Reduction of nitrates in raw material	52	0	95	5,819
		Decorating Furnace Annealing Furnace	Gas Gas		None	None				

Note: HO = Current heavy oil, DHO = Desulfurized heavy oil, DEHO = Desulfurized and emulsified heavy oil

Table 5.3.2 (5) Control Measures for the 25 Establishments (5/6)

#	NAME OF ESTABLISHMENT	NAME OF FACILITIES	FUEL IN USE	CAPACITY (ton/hr)	CONTROL MEASURES		REDUCTION			INVEST.
					IMPROVEMENT OF COMBUSTION EQUIPMENT	FUEL CHANGE OR OTHERS	NOX (%)	SO2 (%)	PM (%)	(1000 US$)
17.	Rubber Products Factory	Water Tube Boiler	HO	10.00	1 Exhaust gas recirculation 2 Supplementation/Improvement of combustion control instruments	A: HO → 50% HO +50% Diesel	44	41	30	98
						B: → DHO	22	73	30	
						C: → DEHO	55	73	65	
18.	Paper Factory	Water Tube Boiler Water Tube Boiler	HO HO	16.00 14.00	1 Low-NOx burner 2 Exhaust gas recirculation 3 Supplementation/Improvement of combustion control instruments	A: HO → 50% HO +50% Diesel	60	41	40	594
						B: → DHO	30	73	20	
						C: → DEHO	61	73	60	
19.	Paper Products Factory (A)	Water Tube Boiler Water Tube Boiler x 3	HO HO	9.40 7.80	1 Portable O2 analyzer (Low air ratio combustion) 2 Low-NOx burner 3 Two-stage combustion 4 Supplementation/Improvement of combustion control instruments 5 Exhaust gas recirculation	A: HO → 50% HO +50% Diesel	44	41	20	734
						B: → DHO	20	73	20	
						C: → DEHO	55	73	40	
20.	Paper Products Factory (B)	Water Tube Boiler Water Tube Boiler	HO HO	9.50 8.2	1 Low-NOx burner 2 Combustion control using automatic O2 analyzer	A: HO → 50% HO +50% Diesel	44	41	20	323
						B: → DHO	20	73	20	
						C: → DEHO	55	73	40	
21.	Metal Products Factory (A)	Heating Furnace Heating Furnace	Gas Gas	10.00 8.00	1 Low-NOx burner 2 Installation of recuperator	None	30	0	20	784
22.	Metal Products Factory (B)	Melting Furnace	Gas	20.00	1 Self-repair of furnace/boiler 2 Installation of bag filter	None	5	0	50	143
		Melting Furnace x 4 Heat Treating Furnace x 5	Gas Gas	1.75	None	None				

Note: HO = Current heavy oil, DHO = Desulfurized heavy oil, DEHO = Desulfurized and emulsified heavy oil

Table 5.3.2 (6) Control Measures for the 25 Establishments (6/6)

#	NAME OF ESTABLISHMENT	NAME OF FACILITIES	FUEL IN USE	CAPACITY (ton/hr)	CONTROL MEASURES			REDUCTION			INVEST.
					IMPROVEMENT OF COMBUSTION EQUIPMENT		FUEL CHANGE OR OTHERS	NOX (%)	SO2 (%)	PM (%)	(1000 US$)
23.	Food Products Factory	Water Tube Boiler x 2	HO	45.40	1	Low-NOx burner	A: HO → 50% HO +50% Diesel	43	40	20	1,317
					2	Exhaust gas recirculation	B: → DHO	20	72	20	
					3	Supplementation/Improvement of combustion control instruments	C: → DEHO	55	72	40	
					4	Installation of telemetric monitoring system					
		Heat Medium Boiler x 2	Diesel			None	None				
24.	Alcoholic Drinks Factory	Water Tube Boiler Water Tube Boiler Water Tube Boiler	HO + Gas HO + Gas HO + Gas	100.00 63.00 27.00	1 2 3	Exhaust gas recirculation Installation of telemetric monitoring system Combustion control using automatic O2 analyzer	A: HO +Gas	47	100	100	1,578
25.	Public Bathhouse	Smoke Tube Boiler x 2	HO	1.30	1	Portable O2 snalyzer (Low sir ratio combustion)	A: HO → 50% HO +50% Diesel	30	41	20	2
							B: → DHO	20	73	20	
							C: → DEHO	44	73	40	
TOTAL											86,000

Note: HO = Current heavy oil, DHO = Desulfurized heavy oil, DEHO = Desulfurized and emulsified heavy oil

5.3.2 Effects and Costs

The pollutant reduction effects by introduction of desulfurized heavy oil and its emulsion are assumed to be as shown in Table 4.2.3.

The estimated pollutant reduction to be achieved through the combined effect of the fuel change and facility improvements at the 25 object establishments are summarized in Table 5.3.3.

Table 5.3.3 Pollutant Reduction Effects in the 25 Establishments

			NOx	SO_2	PM
Present emission (1,000 ton/yr)			11.1	44.1	7.3
Emission after implement-	Fuel	A	6.6	29.2	2.5*1
ation of proposed	improvement	B	6.8	14.0	0.7*1
measures (1,000 ton/yr)	case	C	5.8	14.9	1.6*1
	Fuel	A	40	34	66
Reduction ratio (%)	improvement	B	39	68	90*2
	case	C	48	66	78

Note: *1: Reduction of PM by 3,400 ton/yr by the proposed relocation of one factory is accounted.
*2: EPs are installed in Power Plant (A).

As shown in the Table, the combination of the transient fuel change and facility improvement in Case A is expected to reduce NOx emission by 40%, SO_2 emission by 34%, and PM emission by 66%. In Case B, use of desulfurized heavy oil and installation of EPs in Power Plant (A) will reduce the SO_2 and PM emissions further. But the NOx emission will rather increase above the level of Case A. In Case C, where desulfurized and emulsified heavy oil is used, some more reduction is expected in NOx at 48%.

The expenses for the facility improvements are estimated to be as follows, excluding unestimative expenses such as in-house works, autonomous improvements and factory relocation.

Case A: NOx reduction measures and others
US$ 86,449,000

Case B: Installation of EPs in Power Plant (A)
US$ 77,381,000

Case C: Installation of heavy oil emulsifier in Poweer Plant (A)
US$ 2,113,000

CHAPTER 6 AIR POLLUTION CONTROL PLANNING FOR OTHER STATIONARY SOURCES

6.1 Sources Investigated by the Detailed On-Site Questionnaire

6.1.1 Object Establishments and Facilities

Among the 97 establishments surveyed through the detailed on-site questionnaire, the 72 which remained after the study covered in Chapter 5 are the objects in this section. The breakdown by their types of industry is as shown in Table 6.1.1.

Table 6.1.1 Breakdown of the 72 Establishments by Types of Industry

Type of industry	Number
Food	8
Leather	1
Paper and its products	8
Chemical products	13
Petrochemical products	4
Coal and petroleum products	1
Rubber and plastic products	4
Non-metallic mineral products	6
Basic metals	7
Metal products	3
Transportation equipment	1
Other manufacture	1
Public bath	10
Sports center	1
Hospital	1
Hotel	2
Total	72

Broadly classified, 58 are factories, and 14 are service and commercial establishments. There are 180 furnaces covered by the survey as shown in Table 6.1.2. And there were additionally 16 electric furnaces operated in 6 establishments.

Table 6.1.2 Facilities Investigated by Detailed On-site Questionnaire

Capacity / Type of Furnace	Large	Medium	Small	Micro	Total
Industrial boiler	6	19	46	44	115
Dryer	3	0	9	6	18
Metal melting	1	0	1	1	3
Metal heating	0	5	4	0	9
Ceramic	2	3	10	0	15
Glass melting	6	5	0	0	11
Aggregate dryer	0	0	0	2	2
Heating	1	0	2	2	5
Others	0	2	0	0	2
Total	19	34	72	55	180

6.1.2 Planning Approach

(1) Selection of Survey Objects

In the detailed on-site questionnaire survey, the following features were examined through the simple measurement of the operational status of the combustion facility and the visual inspection of its appearance, with reference made to specifications and operation control records of the facility including fuel consumption, as prepared by the surveyed establishments.

(a) Is the fuel consumption appropriate to the rated capacity of the facility?

(b) Is the facility equipped with operation control instruments?

(c) Is the air ratio proper?

(d) Is the smoke and soot concentration in the flue gas controlled at an appropriate level?

(e) Is the generated heat effectively utilized?

(f) Is there any structural defect harmful to (d) and (e)?

On the basis of the survey results, control measures were studied for 48 establishments, after eliminating 64 furnaces in a total of 24 establishments: 13 establishments that need no measure, 4 under relocation plan, 3 under facility retrofitting or change, 2 in that no measure is possible, and 2 with no reliable data.

(2) Control Measures to be Applied

Control measures are selected from those applied to the sources subjected to the diagnostic survey considering similarity in type of combustion facilities, fuel used, facility size, and operation conditions. As the types of facility not covered by the diagnostic survey program, there are 15 kilns in 4 establishments and 2 gas turbines in 1 plant, and they are all among the eliminated 24 establishments.

Considering that there are many small to medium sized establishments, efforts have been made to select measures that give high pollutant reduction at limited facility investment costs, with emphasis given to the rationalization of operation control.

6.1.3 Control Measures

The twelve measures, as shown in Table 6.1.3, are selected as facility improvement measures for the object facilities.

Table 6.1.3 Facility Improvement Measures

Kind of facility improvement measure	Number of establishments applied (number of facilities)	Unit Cost (US$)
Reduction of combustion chamber loading	3	-
Steam atomizing system	3 (3)	2,200
Burner nozzle renewal	3 (6)	4,700
Fuel preheater	3 (5)	200
NOx measurement device	3	13,600
Combustion control instruments	1 (2)	52,000
In-furnace denitration and flue gas recirculation	1 (2)	66,000
Thermometer for air preheating	1	1,500
HC removal system	1 (paint factory)	63,000
Increase of fuel atomizing air pressure	1	-
Simple repair by owner	4	-
Portable O_2 meter	33	2,400

With respect to fuel change, it is assumed that the current heavy oil is replaced by the desulfurized heavy oil after the start of its supply. The cases postulated in fuel change or improvement are the same as in Chapter 5.

The estimated pollutant reduction to be achieved through the combined effect of the fuel change and facility improvements at the object establishments are summarized in Table 6.1.4.

Table 6.1.4 Pollutant Reduction Effects for the 48 Establishments

			NOx	SO_2	PM
Present emission (1,000 ton/yr)			4.7	11.2	2.6
Emission after implement-ation of proposed measures (1,000 ton/yr)	Fuel improvement case	A	3.5	6.5	2.4
		B	3.7	3.2	2.4
		C	3.6	3.2	2.4
Reduction ratio (%)	Fuel improvement case	A	25	42	7
		B	21	71	7
		C	23	71	7

The expenses for these measures are estimated at approximately US$ 460,000.

6.2 Other Pollution Sources

6.2.1 Object Establishments and Facilities

The establishments for which control measures have been studies so far are mostly large ones covered by the detailed on-site questionnaire and the diagnostic survey. In this section, establishments not included in the above surveys will be considered. They consist of some 7,000 establishments, broken down as shown below, accounting for 25% each of the total consumption of heavy oil and natural gas at stationary emission sources in AMCM.

1) Establishments surveyed by SEDUE as a part of the present Study; 969 firms, 3,336 furnaces,

2) Establishments included in the SEDUE's existing data base; 371 firm excluding those covered by 1)

3) Establishments covered by the DDF's past survey; 6,070 firms excluding those covered by the detailed on-site questionnaire and 4)

4) Bathhouses surveyed by the National Bathhouse Association; 203 bathhouses

Among these, 1) and 2) are mostly factories, and 3) and 4) are service and commercial establishments. Two thirds (2/3) of the combustion facilities for the group 1) are industrial furnaces and 1/3 are boilers. Assuming the same ratio for the group 2), the total number of industrial furnaces is 2,400. Assuming that all of the facilities in the groups 3) and 4) are boilers, the total number of boilers is over 7,500.

6.2.2 Planning Approach

The establishments covered in this Section are large in number but their size and the fuel consumption are relatively small. For this reason, the combustion facility improvement measures are not expected to bring about marked pollutant reduction effect, despite considerable amount of work required.

Therefore, facility improvement measures are to be applied to relatively

large establishments only, and the measures having wide applicability are selected from those measures proposed to the establishments covered by the detailed on-site questionnaire. Therefore, the overall effect of the pollutant emission reduction is largely dependent on the supply of desulfurized heavy oil.

There are 10 relatively large establishments (all covered by the SEDUE's surveys) that are next to the top 20 in the pollutant emission (Figure 3.3.1) subjected to the on-site or the diagnostic survey.

The measure most widely proposed for the on-site surveyed establishments is the introduction of a portable oxygen meter, being proposed to 33 firms among the 48 for which control measures were proposed. The real purpose of this measure is to control the generation of NOx by maintaining appropriate air ratio in combustion. For similar purposes, introduction of other simple equipment and simple facility improvement measures are also taken into consideration.

6.2.3 Outlines of Control Measures

The simple facility improvement measures for operation control effective in reducing pollutant emission are listed in Table 6.2.1.

Table 6.2.1 Simple Facility Improvement Measures

Measures to be applied	Unit Price (US$)
Steam atomizing system	2,200
Fuel preheater	200
Thermometer for air preheating	1,500
Portable O_2 meter	2,400
Simple repair by owner	-

Fuel change is limited to the heavy oil burning facilities as in the case of large factories. But since majority of the firms are of small size, no transitory stage is considered, and the following two cases only are considered.

Case B : Exclusive use of desulfurized heavy oil:

After the supply start of desulfurized heavy oil and when its emulsification is not feasible.

Case C : Exclusive use of desulfurized and emulsified heavy oil:

After the supply start of desulfurized heavy oil and when its emulsification is feasible.

Since the pollutant reduction effects by simple facility improvement measures are not quantifiable unless the actual situation is known, overall effects of fuel change only are shown in Table 6.2.2

Table 6.2.2 Pollutant Reduction Effects by Fuel Change in 7,600 Establishments

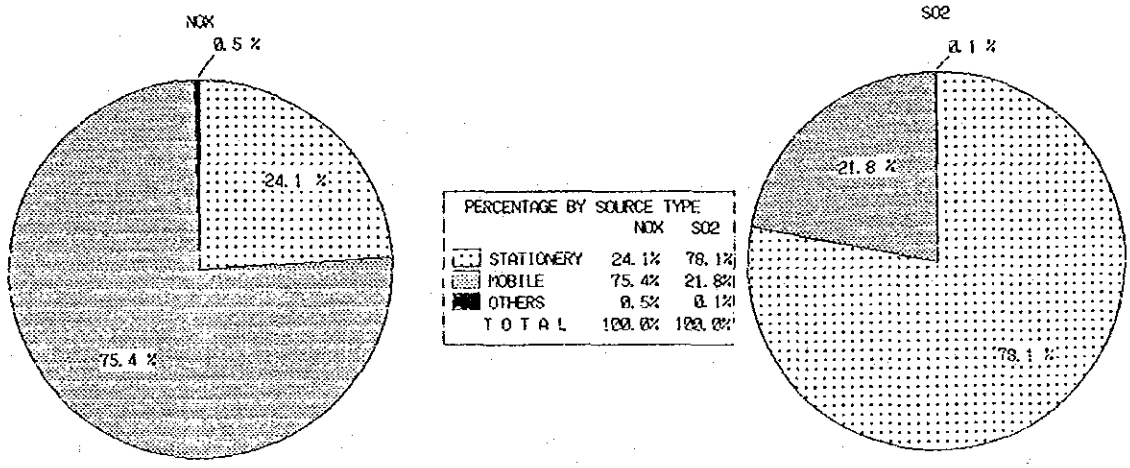
			NOx	SO_2	PM
Present emission (1,000 ton/yr)			5.0	21.0	1.4
Emission after fuel change (1,000 ton/yr)	Fuel change case	B	4.8	7.7	1.2
		C	4.1	7.7	1.0
Reduction ratio (%)	Fuel change case	B	4	63	14
		C	18	63	28

CHAPTER 7 PLAN FOR CONTROL OF STATIONARY AIR POLLUTION SOURCES IN THE METROPOLITAN AREA

7.1 Outline of the Plan

7.1.1 Object Sources for air Pollution Control

According to "Integrated Program Against Atmospheric Pollution in the Mexico City Metropolitan Zone - A Common Agreement, October 1990", the stationary air pollution sources in the metropolitan area account for nearly 3/4 of the total emission of SO_2, and 1/4 of that of NOx as shown in Figure 7.1.1.



NOx Emission SO_2 Emission

Figure 7.1.1 Shares of Stationary Sources in Emission of NOx and SO_2

These pollutants are emitted mainly through fuel combustion. Fuel consumption and the pollutant emission from stationary combustion facilities obtained through this Study's investigation and the SEDUE's past investigation are summarized in Table 7.1.1

Table 7.1.1 Fuel consumption and Pollutant Emission in Stationary Air Pollution Sources (1990)

Fuel Consumption	Heavy oil	($10^3 m^3/yr$)	1,100
	Natural gas	($10^6/m^3/yr$)	3,300
Pollutant Emission	NOx	(10^3 ton/yr)	21
	SO_2	(10^3 ton/yr)	76
	PM	(10^3 ton/yr)	11

A total of about 8,000 establishments are covered by the present Study including 1,400 factories, nearly all the factories having air pollutant emitting facilities in the metropolitan area, and about 70% of the service and commercial establishments in the area having such facilities.

With the large scale establishments preferentially included in the investigation, these 8,000 establishments are considered to represent sufficiently the overall situation of stationary pollution sources in the metropolitan area.

7.1.2 Fuel Improvement Measures

(1) On-going Oil Desulfurization Project

PEMEX has a plan of constructing a hydro-desulfurization plant for heavy oil in the Tula refinery near the metropolitan area. When this project is implemented, a low sulfur heavy oil (S: 0.8%) will be supplied in AMCM and supply of the current heavy oil (S: 3.0 - 3.5%) will be ceased.

This project is one of the themes that were presented in the "Integrated Program Against Atmospheric Pollution in the Mexico City Metropolitan Zone - A Common Agreement" publisehd in October 1990, and is underway with the common agreement among the authorities concerned including the energy, finance and environmental sectors of the Government. Produced desulfurized heavy oil (DHO) is expected to be used as an effective means of stationary pollution source control, by making available to all consumers including small-to-medium-sized establishments under the present system of fuel supply in Mexico which is unitarily carried out by PEMEX.

When the fuel demand at the time of the operation start of the projected desulfurization plant is assumed to be unchanged from 1990 and the composition of fuel kinds is also assumed to remain unchanged, and the currently used heavy oil is totally replaced by desulfurized heavy oil (DHO), the amount of pollutant emission is estimated to be as shown in Table 7.1.2.

Table 7.1.2 Pollutant Emission Reduction by Changing Current Heavy Oil to Desulfurized Heavy Oil

Pollutant	Emission from stationary sources (1,000 ton/yr)		Reduction ratio (%)	
	Present	Future	Stationary sources	All Sources
NOx	20.8	20.1	5	1
SO_2	76.3	23.2	70	55
PM	11.3	10.3	9	-

The above reduction ratios are based on the assumption that the improvement in the quality of heavy oil will reduce SO_2 emission by 73%, NOx emission by 10%, and PM emission by 20% per unit amount of heat. The total SO_2 emission is expected to decrease to a half.

(2) Fuel Change

The replacement of heavy oil with DHO is postulated as the mainstay in this Study in the medium to long-term fuel improvement measures, while the pollution reduction effect, fuel cost and the PEMEX's policy of natural gas usage are taken into consideration. And the change to diesel or natural gas is limited to special cases. However, since the use of DHO is directed to the reduction of SO_2, and not sufficient in reducing NOx and PM, additional measures are required. As a measure to reduce NOx and SO_2 emissions through fuel improvement, the emulsification of heavy oil is considered. However, since the effect of this measure is basically dependent on the quality of the oil used and method of combustion, and there are not many examples of practical application in Japan, the result of the principle test conducted in the present Study should be further verified by the commercial scale test in order to assure the effectiveness when applied to Mexican heavy oil.

Since the supply of DHO will start in 1995 according to the current schedule, partial replacement of the current heavy oil by diesel or natural gas is proposed as an interim measure. This means the replacement of the combustion facilities for heavy oil by those for mixed combustion of heavy oil and diesel or natural gas. Therefore, the applicable facilities are limited to relatively large ones. Specifically, this measure is proposed to those establishments where the diagnostic survey or the detailed on-site questionnaire was conducted.

Other fuel change patterns are also considered depending on the situation of individual sources such as that where mixed combustion of heavy oil and natural gas is currently practiced. Specific proposals in fuel change are given in Table 7.1.3.

Table 7.1.3 Proposed Fuel Change Patterns

Fuel change pattern	Category of applicable pollution sources	Applicable pollution source (Visit No.)
From HO to Case A: HO 50% + D or NG 50% Case B: DHO Case C: DEHO	Establishments surveyed by the diagnostic survey or the detailed on-site questionnaire.	40 establishments of the visit number: (3, 5, 8, 9, 10, 12, 14, 15, 16, 18, 21, 22, 28, 29, 30, 32, 34, 37, 38, 42, 43, 48, 52, 65, 67, 68, 73, 75, 76, 78, 81, 83, 84, 87, 89, 91, 92, 93, 95, 96)
From HO to Case A: HO 50% + D or NG 50% Case B and C: DHO	Ditto	Paper (27) Basic metals (51, 56) Other Manufacture (64)
From HO to Case A: HO 50% + NG 50% Case B and C: DHO 50% + NG 50%	Ditto	Cement (41)
From HO to Case A, B, C: D or NG	Ditto	Chemicals B (62)
From NG 80% + HO 20% to Case A: same as present Case B: NG 50% + DHO 50% Case C: NG 50% + DEHO 50%	Ditto	Power Plant A (69)
From NG 80% + HO 20% to Case A: same as present Case B: NG 80% + DHO 20% Case C: NG 80% + DEHO 20%	Ditto	Power Plant B (70)
From HO to Case A: HO (same as present) Case B: DHO Case C: DEHO	Others	Many

Note: 1) HO = heavy oil, D = diesel, NG = natural gas
DHO = desulfurized heavy oil, DEHO = desulfurized and emulsified heavy oil
2) Case A applies for the period before the start of supply of DHO.
3) Case B or Case C is applied after the start of supply of DHO.
4) Case C requires verification of effects of DEHO.

7.1.3 Managerial Measures

(1) Factory Relocation

Among the 97 establishments surveyed by the diagnostic survey program and/or by the on-site questionnaire program, shut-down of one factory and relocation of one factory were determined through the administrative order. Voluntary relocation is planned by three factories. Although relocation means only the displacement of pollution sources and not reduction of pollutant emission, it is an effective measure for improvement of air quality in AMCM.

In addition, when a huge cost is required in air pollution control by extensive modification of old facilities, renewal of facilities associated with relocation can be more positively evaluated in economical viewpoint. In such a case, factory relocation is a good alternative in air pollution control, and therefore taken into consideration.

(2) Operation Management

The first effective step in the NOx control is to maintain an appropriate air ratio in combustion. It must be fully understood by operation managers and operators. It is necessary that the administrative authority and company managers cooperate in establishing a guidance system for the dissemination of usage of measuring instruments and the methods of combustion control based on the measurements.

7.1.4 Facility Improvement Measures

(1) Combustion Facilities

The following 23 measures are proposed for facility improvement to the establishments covered by the diagnostic survey or the detailed on-site questionnaire survey, and these measures are also proposed to other pollution sources where the effects are expected.

1) Introduction of operation control and monitoring devices

- ◦ Portable oxygen meter (38 establishments)
- ◦ NOx meter (3 establishments)

- Automatic oxygen meter (9 establishments)
- Thermometer for air preheating (1 establishments)
- Combustion control meters (installation or improvement) (11 establishments)
- Telemeter for flue gas monitoring (10 establishments)

2) Improvement of combustion system for NOx control

- Low-NOx burner (11 establishments)
- Flue gas recirculation (13 establishments)
- Two-stage combustion (2 establishments)
- Off-stoichiometric combustion (3 establishments)
- In-furnace denitration combustion (3 establishments)
- Steam injection (2 establishments)
- Burner nozzle replacement (4 establishments)
- Reduction of volumetric load of combustion chamber (6 establishments)
- Installation of precalciner (1 establishment)
- Increase of fuel atomizing air pressure (2 establishments)

3) Improvement of combustion efficiency

- In-house repair (5 establishments)
- Improvement of heat insulation of furnace ceiling (3 establishment)
- Installation of fuel preheater (4 establishments)
- Installation of air preheater (1 establishment)
- Installation of recuperator (2 establishments)

4) Flue gas treatment

- Bag filter (2 establishments)
- Electrostatic precipitator (4 establishments)

(2) Pollution Sources Other Than Combustion Facilities

As pollution control measures for non-combustion facilities, hydrocarbon removal measures are proposed to Chemical Products Factory (C) which has been covered by the diagnostic survey. The measures consist of a hydrocarbon incinerator and a leak prevention measure by cooling.

7.1.5 Effects of Control Measures

The proposed measures for fuel improvement and facility improvement for all the stationary sources are summarized in Table 7.1.4.

Table 7.1.4 Summary of Fuel and Equipment Improvement Plans

Case	Power Plant (A)		Other Sources	
	Fuel use	Equipment improvement	Fuel use	Equipment improvement
Present	HO 20% NG 80%	None	Various	None
A	same as above	Low-NOx measures	A in Table 7.1.3	Low-NOx measures and others
B	DHO 50% NG 50%	Low-NOx measures + EP	B in Table 7.1.3	
C	DEHO 50% NG 50%	Low-NOx measures	C in Table 7.1.3	

Note: (1) HO = current heavy oil, DHO = desulfurized heavy oil
DEHO = desulfurized and emulsified heavy oil
NG = natural gas
(2) Case A applies to the period up to the start of supplying DHO.
(3) Case B or Case C applies after the start of supplying DHO.
(4) Case C requires verification of effects of DEHO.

Table 7.1.5 shows the pollutant reduction effect in Power Plant (A) and all the stationary sources for each of the above cases.

Table 7.1.5 Effect of Pollution Control Plans

Source	Case	Pollutant emission (1,000 ton/yr)			Reduction ratio (%)		
		NOx	SO_2	PM	NOx	SO_2	PM
Power Plant (A)	Present	5.2	17.6	2.1	0	0	0
	A	3.6	17.6	2.1	30	0	0
	B	3.8	9.6	0.3	27	45	87.5
	C	3.0	10.6	1.3	42	40	37.5
All stationary sources	Present	20.8	76.3	11.3	0	0	0
	A	15.1	56.7	6.4*	27	26	43
	B	15.3	24.9	4.4*	26	67	61
	C	13.5	25.8	5.1*	35	66	55

Note : * Includes the reduction of 3,400 ton/yr at one factory for which plant relocation is proposed.

In the transient Case A, although the emissions of SO_2 and PM can not be reduced in the Power Plant (A), NOx is expected to decrease by 30%, and all

the three pollutants are expected to decrease in all the stationary sources combined by at least one-fourth. After the start of supply of DHO, Case C is more advantageous in the reduction of NOx, and Case B brings about more reduction of PM than Case C. Case C requires verification of reduction effect and cost effectiveness of emulsified combustion of DHO, therefore, thorough considerations should be made.

7.2 Capital Requirements and Implementation Schedule

7.2.1 Equipment Investment

(1) Investment Amount

The total amount of investments for facility improvements proposed to the establishments investigated through the diagnostic survey and/or the detailed on-site questionnaire is shown in Table 7.2.1 for the two cases described previously: Case B and Case C.

Table 7.2.1 Investment Amount for Facility Improvements

	Case C : DEHO in Power Plant (A)		Case B : EP in Power Plant (A)	
	Investment (million US$)	Ratio (%)	Investment (million US$)	Ratio (%)
Foreign portion	28.208	33	26.611	16
Local portion	58.241	67	135.106	84
Total	86.449	100	161.717	100

Note: Emulsification of desulfurized heavy oil to make DEHO for the Power Plant (A) is assumed to be carried out by the plant itself in Case C.

The investment amounts shown in Table 7.2.1 are the totals of the estimations for individual establishments for each of which control measures are proposed to each of the surveyed combustion facilities. There are 19 establishments where the estimated investment exceeds US$ 100,000, and 11 establishments, as shown in Table 7.2.2, where the amount exceeds US$ 1 million. As indicated, the establishments where a large investment is required are also emitters of large amount of pollutants.

In the case when EPs are installed in Power Plant (A), the additional investment is about US$ 76 million, making the total for the plant close to US$ 90 million. There considered to be some more establishments, besides those subjected to the detailed on-site questionnaire and the diagnostic survey, where facility improvement is possible and effective. But since they are considered to be rather small establishments, operation improvements by introduction of operation monitoring instruments are more suitable than substantial equipment improvements. Because such improvements require only minor equipment investment, the total investment amount for all the stationary pollution sources is not expected to exceed US$ 100 - 200 million.

Table 7.2.2 Establishments With Facility Investment Exceeding US$ One Million

Rank	Establishments (Visit No.)	Investment (million US$)	Rank in emission		
			NOx	SO_2	PM
1	Cement (41)	45.082	2	2	4
2	Power Plant (A) (69)	13.043	1	1	2
3	Power Plant (B) (70)	6.778	4	4	8
4	Glass (C) (23)	5.819	6	-	11
5	Glass (A) (68)	3.009	13	9	9
6	Glass (B) (31)	2.522	9	-	13
7	Alcoholic Drinks (47)	1.578	11	6	10
8	Chemicals (A) (1)	1.420	21	-	22
9	Petrochemicals (B) (8)	1.350	14	5	19
10	Foods (65)	1.317	32	12	30
11	Petrochemicals (A)(16)	1.058	15	10	29

Note: The investment amount in Power Plant (A) corresponds to the case when emulsification of desulfurized heavy oil is carried out by the plant itself.

(2) Evaluation of Scale of Equipment Investment

To evaluate the scale of the proposed equipment investment, first, the amount of national fixed capital formation was extracted from the economic statistics in Mexico, and then, its equipment investment portion was compared with the amount estimated in this Study for the proposed pollution control measures.

The latest statistic figure for the GDP in Mexico is 494,054,824 million pesos in 1989 according to the temporary report of INEGI, or about US$ 200 billion, as converted by the average exchange rate of that year, i.e. 2,453.2 pesos/US$. Since the figure for the fixed capital formation in that year was not available, its ratio to GDP at 18.9% in 1987, with 13.4% for private and 5.5% for government, was used to estimate the national fixed capital formation in 1989 to be about US$ 38.0 billion.

The breakdown of this fixed capital formation is estimated based on the statistics in 1983 - 1984 as follows:

Domestic : 91.8%

Construction : 63.2%

Transportation equipment : 8.9%

General equipment : 19.7%

Import : 8.2%

Transportation equipment : 1.0%

General equipment : 7.2%

The investment in air pollution control belongs to the general equipment sector whose share in the total fixed capital formation is 26.9% by adding the domestic and the import portions. The amount in the equipment sector is therefore, US$ 38.0 billion x 26.9% = US$ 10.2 billion or about US$ 10 billion.

Of this amount, the total pollution control investment as estimated previously at US$ 100 - 200 million constitutes only 1 - 2%.

7.2.2 Organization for Implementation

The control measures recommended in this Study can be broadly classified into the following three categories, all requiring human resources and capital investments.

1) Management improvement measures

2) Fuel change measures

3) Equipment improvement measures

The main responsibility in implementing these measures should naturally be assumed by the enterprisers who own and operate combustion facilities, and the extra expenses for implementing air pollution control measures should be considered as a part of the production or service cost.

In the case of private establishments, however, they may not be positive in implementing the measures because higher cost means lower competitiveness. Considerable amounts of investment proposed to certain types of industry may be heavy financial burdens to them at least temporality. In addition, there are not sufficient number of experts in the air pollution control technology, and individual establishments may not be

able to secure these experts by themselves.

To overcome these difficulties, it is desirable to make organizational arrangements that induce enterprisers to make unified efforts and facilitate procurement of equipment funds and introduction of air pollution control technologies. Such organizational function may be assumed by existing associations such as the National Bathhouse Association (CANAIBAL), or if possible, new organizations may be established.

The role of administrative authorities include provision of subsidiary measures in the both aspects of human resources and capital resources to promote implementation of the control measures by enterprisers and to bring about sustained effects of those measures.

As economic incentive measures, the tax reduction systems for plant relocation and acquisition of pollution control equipment were introduced in Mexico and carried into effect for a certain period of time in the past. Recently, a low-interest financing program for such activities has been started and implemented for some types of industry. As additional measures to develop human resources and air pollution control technologies, the following are recommended:

1) Training for combustion control

2) Training for air pollution control

3) Consultation for equipment improvement

4) Training for exhaust gas measurement

5) Leasing of exhaust gas measuring instruments

6) Interest subsidy and favorable taxation on pollution control investment

7.2.3 Time schedule for Implementation

Because the proposed air pollution control measures are classified into two groups, i.e., those to be carried out by the initiative of individual establishments, and those whose implementation is dependent on the availability of desulfurized heavy oil, the overall implementation schedule is proposed to be as follows:

Phase 1 : up to 1995

1) Installation of basic combustion control instruments

2) Training of combustion and air pollution control engineers and technicians

3) Transient fuel change

4) Provision of stimulative measures such as low-interest loans and favorable tax system

5) Installation or leasing of exhaust gas measuring instruments

6) Plant relocation

7) Implementation of the facility improvement measures including low-NOx measures

8) Verification of new control technologies

9) Consolidation of the administrative organizations

Phase 2 : after 1995

1) Fuel change

2) Consolidation of the stimulative measures

3) Implementation of advanced measures for improvement of combustion facilities and combustion methods

7.3 Recommendation

For the effective implementation of the proposed plan for controlling stationary sources of air pollution in the Metropolitan Area of the City of Mexico, the following actions are highly recommended.

(1) Installation of Basic Measuring Instruments in Combustion Facilities

Virtually all of combustion facilities in AMCM are not equipped with a fuel flow meter which is an indispensable tool for effective combustion control. Installation of the flow meter should be made obligatory.

Other basic instruments that are usually not provided include the pressure gauges and the thermometers for fuel and combustion air and the pressure gauge for fuel atomizing steam. If provided, most of them employ percent-scale indicators rather than indicating actual values, making operation monitoring difficult.

Installation of these gauges and meters should also be made obligatory with the indicators showing actual values compensated for barometric pressure.

(2) Provision of Exhaust Gas Measuring Instruments for Monitoring of Pollutant Emitting Facilities

Factories having pollutant emitting facilities of large capacity should be obliged to install continuous measuring devices for the flue gas velocity and concentration of pollutants in the flue gas including CO, CO_2, NOx, smoke and soot, and NOx. A telemetric monitoring system should be established through which the measured data are transferred to a monitoring center of SEDUE.

Establishments having pollutant emitting facilities of small-to-medium capacities should have a flue gas oxygen analyzer for routine measurement. Concentration of CO_2, CO, smoke and soot, and NOx in the flue gas should be also measured at an appropriate interval. The results should be periodically submitted to the responsible government agency.

(3) Guidance for Combustion Control

Guidance should be given to the engineers in stationary sources by the combustion technology specialists on the control of pollutant generation and emission from combustion facilities and on the methods of energy saving. As a first step, importance of the appropriate air-fuel ratio in combustion should be realized by the engineers at the sources. It can be realized through such a practice as measuring concentration of CO, NOx and smoke and soot in the flue gas at varying concentration of oxygen and constructing a chart showing their relationship. Early conduct of this practice with obligatory submission of the result is highly recommended.

(4) Technical Consolidation in the Administrative Sector

1) Establishment of Industrial Pollution Control Assistance Center

It is desirable to establish an "Industrial Pollution Control Assistance Center (IPCAC: tentative name)" attached to SEDUE which assumes a leading role in implementation of the activities stated above by extending assistances and guidances to concerned sectors in control of industrial pollution.

The Government of Mexico has a plan to establish an "Environmental Research and Training Center (ERTC: tentative name)" which deals with various environmental problems including air quality, water quality, solid wastes and hazardous wastes. If ERTC is to be established, IPCAC may be positioned as a part of ERTC.

Functions of IPCAC concerning air pollution include the following:

i) inspection and authorization, selling, renting and leasing of exhaust gas measuring instruments, and technical training for the measurement

ii) technical guidance for industrial pollution control

iii) training of the experts who assume the above roles

2) Fosterage of Personnel for Exhaust Gas Inspection

It is highly important for the administrative sector to know technical

realities concerning emissions of pollutants at stationary sources. Accordingly, it is indispensable for the relevant sections of SEDUE, DDF, and GEM to have competent technical personnel for inspection of the emissions at stationary sources. These personnel should be fostered and reasonably treated, desirably as permanent employees, so that the technical knowledge in this field is accumulated within the administrative sector.

3) *Consolidation of Emission Inventory*

The existing inventory data for stationary air pollution sources in AMCM are considered to be not adequate in terms of the number of sources covered, data items, and accuracy of the data. Preparation of a comprehensive emission inventory of the Metropolitan Area under cooperation of SEDUE, DDF and GEM is recommended.

(5) Practical Application of Stationary Source Control Technologies

The control technologies of stationary pollution sources proposed in this Study include 1) two-stage combustion type low-NOx burners for heavy oil, and 2) emulsified heavy oil combustion, as well as others including exhaust gas recirculation, two-stage combustion, off-stoichiometric combustion, in-furnace denitration combustion, and burners atomized with natural gas for furnaces with particularly high NOx concentration such as glass melting tank ovens.

Since the desulfurized heavy oil scheduled to be supplied from 1995 will have still a high content of nitrogen, combination of the measures for reducing fuel NOx and thermal NOx is indispensable.

The two-stage combustion type low-NOx burner is effective in reducing fuel NOx, and therefore, its early development is recommended.

Effects of emulsified combustion as a measure to reduce thermal NOx and smoke and soot are technically recognized. But since there are not many practical examples in Japan, a careful study is necessary on the applicability of this technology to the Mexican heavy oil. A laboratory-scale test conducted in the present Study confirmed the effects of this technology. In order to apply the emulsified combustion of the Mexican heavy oil to industrial boilers and furnaces in Mexico, it is necessary to

carry out a feasibility study including a pilot-scale test and practical application tests.

(6) Economic Incentives for Pollution Control Investment

Since investments in environmental pollution control generally do not bring about economic benefits to business establishments, it is desirable to introduce economic measures such as financial assistance and tax incentives that indirectly promote such investment. It is desirable that the favorable taxation system once adopted in Mexico be re-introduced and the existing low-interest credit system be consolidated.

(7) Control of Stationary Sources and Mobile Sources

This Study has been concerned with the control of stationary air pollution sources, and priorities have been given to the reductions of NOx and PM emissions. The amount of emission of NOx from mobile sources is said to make up three-quaters of the total emission in AMCM. Against this situation, the Mexican Government has established an emission control program applicable to new automobiles of respective models. Long-term effects are expected if this program is implemented steadily. On the other hand, implementation of the control measure for stationary sources brings about immediate effects although the total NOx emission is smaller than that from mobile sources. Therefore, early implementation of stationary source control measures is highly desirable.