THE STUDY
ON
[illegible] TECHNOLOGIES FOR
THE AIR POLLUTION CONTROL OF
[illegible]
IN
THE METROPOLITAN AREA OF
THE CITY OF MEXICO

Final Report

Summary

JAPAN INTERNATIONAL COOPERATION AGENCY (JICA)

NATIONAL INSTITUTE OF ECOLOGY
THE UNITED MEXICAN STATES

THE STUDY ON THE COMBUSTION TECHNOLOGIES FOR THE AIR POLLUTION CONTROL OF STATIONARY SOURCES IN THE METROPOLITAN AREA OF THE CITY OF MEXICO

Final Report

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SEPTEMBER 1995

PACIFIC CONSULTANTS INTERNATIONAL, TOKYO
In association with
JAPAN ENVIRONMENT ASSESSMENT CENTER CO., LTD., TOKYO

In this report, project costs are estimated based on July 1995 prices with an exchange rate of 1 US$ = N$6.00 (= ¥90)

PREFACE

In response to a request from the Government of the United Mexican States, the Government of Japan decided to conduct the Study on the Combustion Technologies for the Air Pollution Control of Stationary Sources in the Metropolitan Area of the City of Mexico in the United Mexican States and entrusted the study to the Japan International Cooperation Agency (JICA).

JICA sent a study team led by Dr. Akira Uchida of Pacific Consultants International (PCI) and organized by PCI and Japan Environment Assessment Center Co., Ltd. to the United Mexican States five times between June 1993 and August 1995.

The team held discussions with the officials concerned of the Government of the United Mexican States, and conducted field surveys. After returning to Japan, the team conducted further studies and compiled the final results in this report.

I hope that this report will contribute to the promotion of the plan and to the enhancement of friendly relations between our two countries.

I wish to express my sincere appreciation to the officials concerned of the Government of the United Mexican States for their close cooperation throughout the study.

September 1995

Kimio Fujita

Kimio Fujita
President
Japan International Cooperation Agency

THE STUDY ON THE COMBUSTION TECHNOLOGIES FOR THE AIR POLLUTION CONTROL OF STATIONARY SOURCES IN THE METROPOLITAN AREA OF THE CITY OF MEXICO

September 1995

Mr. Kimio Fujita
President
Japan International Cooperation Agency

LETTER OF TRANSMITTAL

Dear Sir,

We are pleased to submit to you the final report entitled "The Study on the Combustion Technologies for the Air Pollution Control of Stationary Sources in the Metropolitan Area of the City of Mexico". This report has been prepared by the Study Team in accordance with the contract signed on 8 June 1993, 23 May 1994, and 8 May 1995 between Japan International Cooperation Agency and Pacific Consultants International.

The report examines the existing conditions concerning air pollution and stationary air pollution sources in the metropolitan area, analyzes the results of the combustion tests in the test plant, and proposes the combustion technologies for the air pollution control of stationary sources in the metropolitan area.

The report consists of the Summary, Main Report, Data Book, and Operation and Maintenance Manual for Combustion Test Plant. The Summary summarizes the results of all studies. The Main Report presents the results of the whole study including analysis of background conditions, evaluation of the present state of stationary air pollution sources, analysis of results of the combustion tests, proposals on improvement of combustion technology and institutional reinforcement for its dissemination. The Data Book contains detailed technical data. An Operation and Maintenance Manual for the combustion test plant has been also prepared.

All members of the Study Team wish to express grateful acknowledgments to the personnel of your Agency, Ministry of International Trade and Industry, Ministry of Foreign Affairs, and Embassy of Japan in Mexico, and also to officials of the Government of Mexico for their assistance extended to the Study Team. The Study Team sincerely hopes that the results of the study will contribute to the improvement of the air quality and the social development in the Metropolitan Area of the City of Mexico.

Yours faithfully,

内田 顕

Akira Uchida
Team Leader

ACRONYMS

Administrative Areas

DF : Distrito Federal (Federal District)

EDOMEX : EM

EM : Estado de Mexico (State of Mexico)

MCEM : Municipios Conurbados del Estado de Mexico (17 cities of the State of Mexico within ZMCM)

ZMCM : Zona Metropolitana de la Ciudad de Mexico (Metropolitan Zone of the City of Mexico = DF + MCEM)

Organizations

CENAM : Centro Nacional de Metrología (National Metrology Center)

CFE : Comision Federal de Electricidad (Federal Commission for Electricity)

CONAE : Comision Nacional para Ahorro de Energia (National Commission for Energy Saving)

DDF : Departamento del Distrito Federal (Department of Federal District)

GEM : Gobierno del Estado de Mexico (Government of the State of Mexico)

IIE : Instituto de Investigaciones Electricas (Institute of Electrical Investigation)

IMP : Instituto Mexicano del Petroleo (Mexican Institute of Petroleum)

INE : Instituto Nacional de Ecologia (National Institute of Ecology)

JICA : Japan International Cooperation Agency

METROCOM : Comision Metropolitana para la Prevencion y Control de la Contaminacion Ambiental en el Valle de Mexico (Metropolitan Commission for Prevention and Control of Environmental Pollution in the Mexico Valley)

NIST : National Institute of Standards and Technology (USA)

PEMEX : Petroleos Mexicanos (Mexican Petroleum)

PROFECO : Procuraduría Federal de Consumidor (National Prosecutors' Office of Consumer)

PROFEPA : Procuraduria Federal de Proteccion al Ambiente (Federal Prosecutors Office of Environmental Protection)

SE : Secretaría de Energía (Ministry of Energy)

SECOFI : Secretaría de Comercio y Fomento Industrial (Ministry of Commerce and Industrial Development)

SECT : Secretaría de Comunicaciones y Transportes (Ministry of Communication and Transport)

SEDESOL : Secretaría de Desarrollo Social (Ministry of Social Development)

SEG : Secretaría de Gobernacion (Ministry of Home Affairs)

SEMARNAP : Secretaría de Medio Ambiente, Recursos Naturales y Pesca (Ministry of Environment, Natural Resources and Fishery)

SEMIP : Secretaría de Energia, Minas e Industria Paraestatal (Ministry of Energy, Mines and Public Industry)

SEP : Secretaría de Educacion Publica (Ministry of Public Education)

SES : Secretaría de Salud (Ministry of Health)

SHCP : Secretaría de Hacienda y Credito Publico (Ministry of Finance and Public Credit)

SINALP : Sistema Nacional de Acreditación de Laboratorios Pruebas (National System of Testing Laboratories Accreditation)

SPP : Secretaría de Programacion y Presupuesto (Ministry of Planning and Budget)

STPS : Secretaría de Trabajo y Prevision Social (Ministry of Labor and Social Security)

Technical Terms

EGR : Exhaust gas recirculation

FBC : Fluidized bed combustion

NO_2 : Nitrogen dioxide

NOM : Norma Oficial Mexicana (Mexican Official Standard)

NOx : Nitrogen oxides

PM : Particulate matter

PM10 : Suspended particulate matter of diameters less than 10 μm

SO_2 : Sulfur dioxide

SOx : Sulfur oxides

TSP : Total suspended particulates

PICCA : Programa Integral Contra la Contaminacion Atmosferica en la Zona Metropolitana de la Ciudad de Mexico (Integrated Program Against Atmospheric Pollution in the Metropolitan Zone of City of Mexico, METROCOM, October 1990)

IMECA : Indice Metropolitano de la Calidad del Aire (Metropolitan Index of Air Quality)

The Study on the Combustion Technologies for the Air Pollution Control of Stationary Sources in the Metropolitan Area of the City of Mexico

Final Report

Summary

Table of Contents

Chapter 1 Introduction

Metropolitan Zone of the City of Mexico (ZMCM) consists of all 16 wards of the Federal District (DF) and 17 cities of the State of Mexico. ZMCM is one of the largest megalopolises in the world with the population of about 15 million and the area of about 3,600 km^2. The problem of air pollution emerged in ZMCM in parallel with rapid expansion of motorization and industrialization, and became very serious by the middle of 1970s. Besides the large amount of air pollutant emissions, particular conditions of ZMCM in geography, topography, and meteorology also have been excerting negative effects on the air pollution.

In early 1980s, the Mexican Government began to intensify their efforts for abatement of environmental pollution. The Government of Japan has been also providing assistance for mitigation of the air pollution problem by available methods including technical cooperation of Japan International Cooperation Agency (JICA). Meanwhile, air pollution by sulfur dioxide (SO_2) has been considerably improved as a result of measures taken by the Mexican Government. However, the problem of photochemical smog is still unsolved, and therefore, control of emissions of nitrogen oxides (NOx) remains as a subject of vital importance.

This Study was conducted in such context by JICA and the Mexican counterpart organizations including Nationally Institute of Ecology (INE) and Mexican Institute of Petroleum (IMP). The objectives of the Study are as follows:

(1) To propose appropriate combustion control technolgy and methods to reduce emissions of NOx and smoke dust from stationary sources in ZMCM
(2) To transfer such technology from the Study Team to the Mexican counterpart through the conduct of combustion tests in a test plant

The Study Area is ZMCM as shown in Figure 1.1. However, combustion tests were conducted in the laboratory of IPM in Pachuca where the combustion test plant was installed.

The Study began in June 1994 based on the Scope of Work agreed in March 1993 between JICA and the Mexican Authorities. The time schedule for the Study is shown in Table 1.1.

The composition of the Final Report for the Study is as follows:

1) Main Report
2) Summary
3) Data Book
4) Operation and Maintenance Manual for Combustion Test Plant

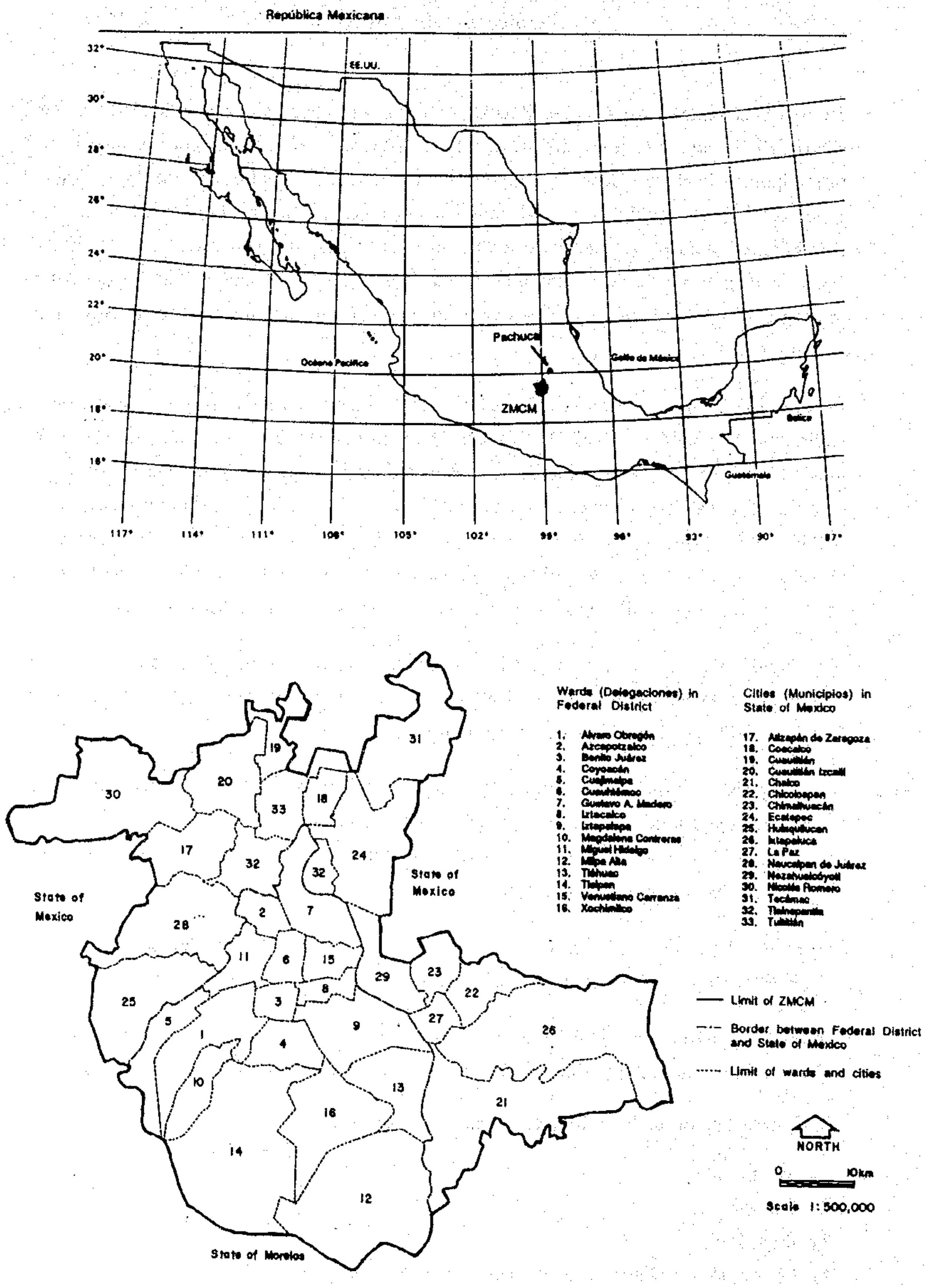
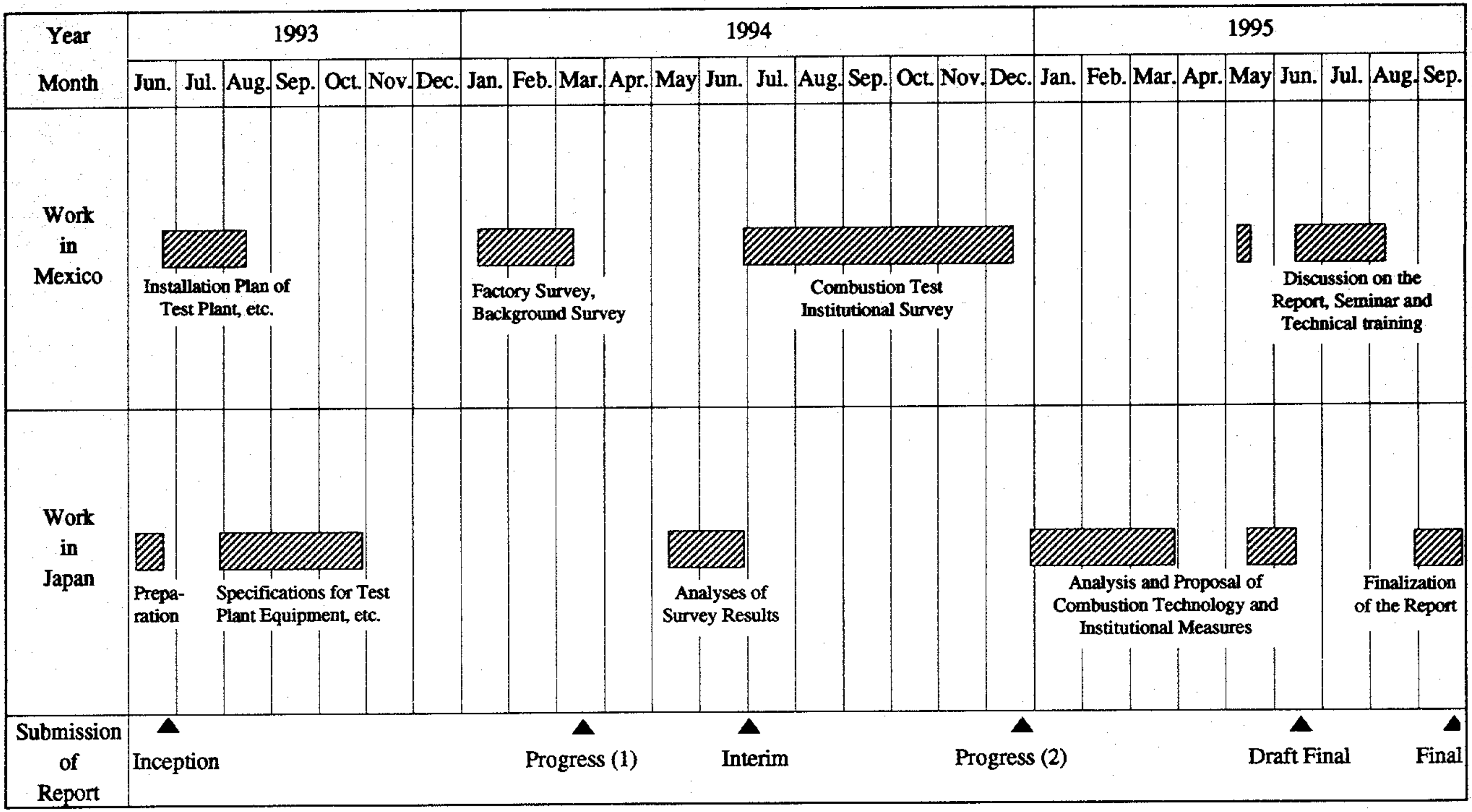


Figure 1.1 Study Area (ZMCM)

Table 1.1 General Time Schedule for the Study



Chapter 2 Outlines and Background of Air Pollution in the Metropolitan Zone of the City of Mexico

2.1 Social and Economic Conditions

The population of ZMCM in 1990 was about 15 million, of which about 8.2 million is in DF and about 6.8 million is in MCEM. Of the total population of about 81 million in the United Mexican States, the population of ZMCM accounts for 18.5%. During the 10-year period from 1980, the population of ZMCM increased by 20%. While the increase in DF in the same period was only 2.6%, the increase in MCEM was remarkable at 52%.

In the national GDP of the manufacturing sector, that of ZMCM was said to be decreased from 31% in 1980 to 27% in 1988. Major types of industry in the manufacturing sector in ZMCM are : foods and drinks, machinery, textile and apparel, and pulp and paper.

2.2 Energy Situation

(1) Energy Policy for Environmental Protection

The Mexican Government has executed various measures in order to protect the atmospheric environment in the ZMCM, derived from the basic policy of the Integrated Program Against Atmospheric Contamination (PICCA: Programa Integral Contra la Contaminación Atmosférica, Oct. 1990).

First of all, heavy oil supply to ZMCM was stopped in December 1991 due to its high content of sulfur. Heavy oil was replaced by natural gas in plants of large-scale energy consumption, and by gasoil or diesel in facilities of small-scale energy consumption, with only one exception. The sulfur content of diesel oil has also been reduced to less than 0.05% by adoption of a direct desulfurization method.

In the public transport sector, it has been recommended that trucks made during 1980 to 1990 be converted to use of gas as fuel, and this measure has already implemented for more than 18,000 vehicles.

In December 1993, the Mexican Government modified the energy supply plan for the ZMCM in accordance with the progress of the heavy oil desulfurization project financed by the Overseas Economic Cooperation Fund of Japan (OECF). The new plan proposes to supply hydro-desulfurized heavy oil (H-oil) from 1998 in place of the gasoil used at the present.

(2) Energy Consumption

Final consumption of energy and its equivalent in Mexico in 1992 was 645 million BOE (barrels of oil equivalent), and this amount corresponds to 73% of the gross domestic supply and 46% of the total production of the primary energy. The total consumption of fuels in ZMCM during the one-year period from April 1993 to March 1994 was 210 million BOE.

Stationary sources of air pollutant emission consist of industry and residential, commercial and public utilities. They consume approximately half of the total energy supplied for final consumption. As for industries, the daily average consumption of fuels was 11.29 million liters in gasoline equivalent during the period from August 1992 to September 1993. Its composition by kind of fuel is as follows:

Natural gas	55.6%
LPG	26.9%
Gasoil	12.8%
Diesel	4.7%

2.3 Present State of Air Pollution in ZMCM

(1) Ambient Air Quality Standards

The ambient air quality standards in Mexico are shown in Table 2.3.1.

Table 2.3.1 Ambient Air Quality Standards in Mexico

Pollutant	Averaging time (hr)	Concentration
Sulfur Dioxide (SO_2)	24	0.13 ppm
Nitrogen Dioxide (NO_2)	1	0.21 ppm
Total Suspended Particulates (TSP)	24	275 $\mu g/m^3$
Carbon Monoxide (CO)	8	13 ppm
Ozone (O_3)	1	0.11 ppm

So that the general population can conveniently understand the degree of air pollution, an index called IMECA (Indice Metropolitano de la Calidad del Aire: Metropolitan Index of Air Quality) is used in Mexico. Conversion of ambient concentration of each pollutant to IMECA is made as follows: 1) the air quality standard value is set as IMECA 100, and concentration zero is IMECA zero, 2) the concentration limit beyond which there is a potential hazard to everyone is set as IMECA 500, 3) actual concentration values are converted to IMECA by linear interpolation.

(2) Trend of Ambient Air Quality in ZMCM

Monthly maximum concentrations of O_3, SO_2, CO and NO_2 in ZMCM since 1991 expressed in IMECA are shown in Figure 2.3.1.

In 1992, heavy oil supply to factories (except a cement plant) in ZMCM was terminated and replaced by natural gas and gasoil, and compulsory installation of a catalytic converter to new model vehicles was started. Implementation of these measures seems to have positive effects. Monthly maximum IMECA values of CO and SO_2 apparently decreased: they are roughly around the level of 50 in 1993 and on. However, there is no significant improvement for ozone: its level still fluctuating around 250 since 1993. NO_2 also has not been improved, the IMECA level is fluctuating around 100.

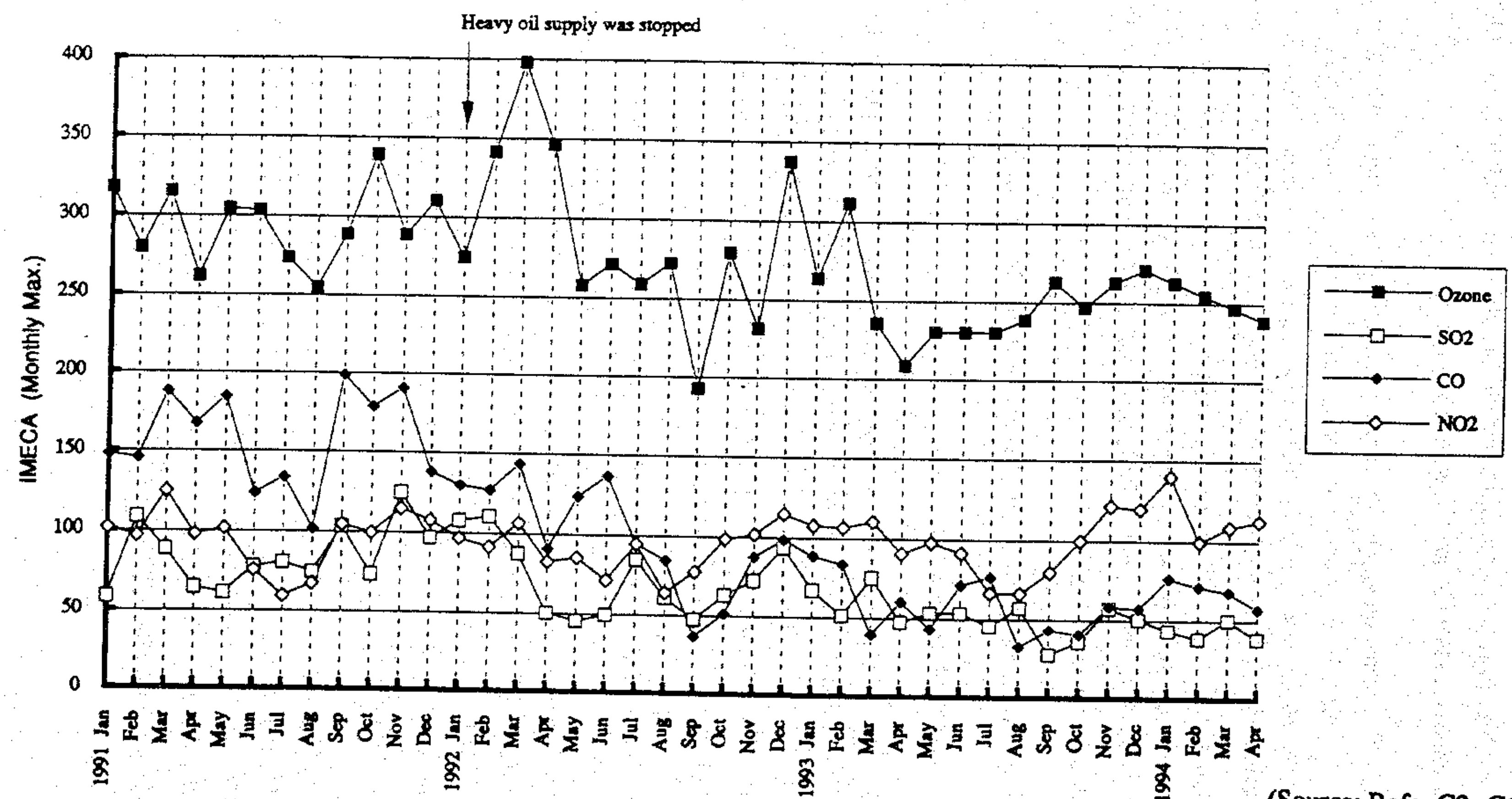
2.4 Institutional Framework for Air Pollution Control

(1) Government Organization

To solve the problems of air pollution in ZMCM, a special commission named the Metropolitan Commission for Prevention and Control of Environmental Pollution in the Mexico Valley (hereinafter called "the Commission" or "METROCOM") was organized. The Commission is composed of representatives of 13 governmental authorities including DDF and GEM.

In October 1990, the Commission established and published a comprehensive air pollution control program for ZMCM named Integrated Program Against the Atmospheric Contamination in the Metropolitan Zone of the City of Mexico (PICCA: Programa Integral contra la Contaminación Atmosférica de la Zona Metropolitana de la Ciudad de México). PICCA, consisting of permanent, temporary and seasonal measures, has been under implementation by the federal, state, and municipal governments.

In respect of environmental protection at the national level, INE is the primarily responsible organization. General Directorate of Environmental Standardization of INE is the main Mexican body of the Steering Committee of the current Study. PROFEPA is responsible for environmental inspection, and controls activities that endanger the environmental condition violating relevant regulations.



(Source: Refs. C2, C6)

Figure 2.3.1 Ambient Air Quality in ZMCM Expressed by IMECA (January 1991 - April 1994)

(2) Pollutant Emission Standards for Stationary Sources

The new emission standards for air pollutants from boilers and other combustion facilities were announced on December 2, 1994, and went into force on the next day. The preceding emission standards issued November 18, 1993 were accordingly replaced by the new standards.

The new NOx emission standards for ZMCM are summarized in the Table 2.4.1. The standard values were loosened as of the end of 1997, and will be finally tightened to stricter levels than the previous ones for some groups according to the size of boilers.

Table 2.4.1 NOx Emission Standards for ZMCM

Capacity (MJ/hr)	Fuel type	Concentration (vol. ppm)		
		Previous	Until Dec.1997	From Jan.1998
up to 5,250	heavy oil, gasoil	NA	NA	NA
	other liquid	NA	NA	NA
	gas	NA	NA	NA
5,251~43,000	liquid	150	220	190
	gas	130	220	190
43,001~110,000	liquid	140	180	110
	gas	120	180	110
above 110,000	solid	NA	160	110
	liquid	130	160	110
	gas	100	160	110

NA: Not applicable
Source : Ref. B3, B6

2.5 General Situation of Stationary Air Pollution Sources

Annual amounts of air pollutant emissions from stationary sources in ZMCM were reported in the literature as of 1989 as being : the share of stationary sources in NOx emission was 24%, SOx emission 78%, and particulates 65%. These figures indicate that stationary sources are a significant contributor to the emissions of SO_2, particulates, and NOx.

The total number of manufacturing industries in ZMCM in 1988 was about 30,000 of which about 22,000 or 72% were in DF and about 8,000 or 28% were in MCEM. The breakdown by scale of industry is shown in Table 2.5.1.

Table 2.5.1 Number of Manufacturing Industries in ZMCM by Size Categories (1988)

Size Category	Number of Industries			Ratio
	DF	MCEM	ZMCM Total	(%)
Large	326	405	731	2.4
Medium	553	249	802	2.7
Small	4,741	1,253	5,994	19.9
Micro	16,204	6,391	22,595	75.0
Total	21,824	8,298	30,122	100.0

Note: Size of industry is classified according to the number of engaged persons as follows:
Large: 251 or more Medium: 101 to 250
Small: 16 to 100 Micro: 15 or less

Source : Ref. A2

2.6 Inspection of Air Pollutant Emissions From Stationary Sources

(1) Results of Official Monitoring

The Industry Verification Program in México Valley was started in July 1992. This program forces all industries located in ZMCM to measure air pollutant emissions once a year and to report the result of measurement to INE. The first step of this program is the submission of the report to INE, and the second step is inspections by PROFEPA. These inspections are made to verify if the submitted emission inventory satisfies the legitimate form, and if the reported data are true. In case important offenses are found, the enterprises can be ordered to partially or fully suspend operation.

From August 1992 to July 1993, PROFEPA completed a total of 8,363 effective inspections under the program. Although this number of industries is only 28% of the total in ZMCM, the numbers of large and medium size industries inspected were 836 and 1,004, respectively. Therefore, most of the significant stationary pollution sources in ZMCM are considered to have been inspected.

As a result of the inspections, 542 industries (6%) were made the objective of sanctions on the basis of there being important offenses, and 6,598 industries (79%) found to have committed lighter offences were given technical recommendations. The industries identified as having no problem were only 1,088 (13%).

(2) Capability of Measurement Service Companies

All industries located in ZMCM are responsible for measurement of air pollutant emissions and for submission of the results to INE. Preparation of emission measurement data is usually entrusted to a measurement service company because most medium-to-small enterprises do not have measuring equipment and qualified staff for measurement.

Measurement companies are required to register with the INE. However, even among registered companies, many do not have authorized measuring devices and standard gases to calibrate the devices. It sometime happens that an enterprise is identified as offending against the emission standards by mistake due to erroneous measurement by a measurement company. Therefore, early legislation is needed for establishment of an inspection and certification system applicable to measurement companies, measuring devices and standard gases, and for establishment of a qualification system of measurement technicians.

2.7 Capacity Development for Combustion Management

(1) Existing Licensing System for Operators of Combustion Eequipment

Personnel to be engaged in the operation of combustion equipment are required to have the qualified status of Plant Master (Jefe de Planta), Operator (Operador) and Fireman (Fogonero) only for boilers by the Regulation for Inspection on Steam Generators and High Pressure Vessels.

The Ministry of Labor and Social Security (STPS) is given the authority to inspect production, repair and operation of steam generators and high pressure vessels. The boilers of specific sizes in specific locations are required to be operated by qualified personnel under the regulation.

(2) Voluntary Capacity Development of Operators

Besides the legal requirement, voluntary development of the abilities of operators is carried out by various sectors. CONAE, the Federal Commission for Energy Saving, offers a periodic training course for the promotion of energy saving in the operation of combustion equipment.

In addition, CONAE has other training courses such as longer retraining courses for engineers and an energy efficiency appraisal course for consulting engineers in collaboration with Autonomous University of Mexico (UAM).

Chapter 3. Investigation of Stationary Air Pollution Sources in ZMCM

3.1 Survey Method

(1) Synoptic Survey of Factories by Questionnaire

This survey was conducted mainly regarding those factories which had been surveyed in the previous JICA study in 1990-1991 (Ref. A10). By the end of September 1993, 47 enterprises submitted responsive answers, concerning a total of 143 combustion facilities.

(2) Diagnostic Survey of Selected Factories

Among the 47 factories, 25 were selected for the diagnostic survey. Flue gas measurement was made at combustion facilities in 13 of those 25 factories. Classification of the selected factories by the kinds of fuel and equipment is as follows:

1) Classification by fuel used

Gas oil	9 factories
Diesel oil	4 factories
Natural gas	12 factories

2) Classification by combustion equipment

Water tube boiler	15 factories
Smoke tube boiler	7 factories
Tank oven for glass melting	1 factory
Rotary kiln	1 factory
Reverberatory furnace	1 factory

Diagnoses of combustion facilities were carried out for the following objectives:

a. Comparison with the results of the previous JICA study with respect to extent of improvement of equipment, fuel used, and combustion control devices

b. Comparison with the NOx emission standards that were tightened after the previous JICA study

c. Measurement of combustion efficiency and its evaluation

d. Determination of the present situation of low-oxygen combustion and its evaluation

(3) Diagnostic Survey of Boilers in Service and Commercial Institutions

In addition to the synoptic and diagnostic surveys of factories, on-site surveys of boilers in service and commercial institutions were conducted. Institutions surveyed were 2 hospitals, a hotel, a medicine firm and a sport center, for a total of 5.

3.2 Summary of Survey Results, and Discussion

(1) Combustion Equipment

1) Installation of Combustion Control Devices

The conditions of use of combustion control devices of boilers for safety and low-NOx operation were analyzed for 94 boilers of 42 enterprises, including 11 diesel-fired, 50 gas-fired and 33 gasoil-fired boilers.

Those enterprises are mainly large to medium size factories and large non-manufacturing facilities. The data were obtained mainly through the questionnaire.

a. Water Level Gauge, Low Water Level Cut-off Device and Automatic Water Supply Device

These devices are installed in 89% or more of the 94 boilers. This installation rate is considerably high. However, gasoil-fired boilers show a relatively low installation rate of 79%. Considering the more urgent necessity of low-NOx operation for gasoil-fired boilers than for gas-fired boilers, this situation should be improved as early as possible.

b. Steam Pressure Gauge

This device is installed in almost all of the facilities.

c. Water Flow Meter, Oil Flow Meter and Gas Flow Meter

These flow meters are essential for knowing the boiler efficiency from hourly water input and hourly fuel consumption. The installation rate of water flow meters was lower for oil-fired boilers, and, in particular, no diesel-fired boiler was equipped with a water flow meter. The installation rate of oil flow meters was also low. In gas-fired boilers, the installation rates of both water flow meters and gas flow meters were 84% or more.

d. Flame Eye (Flame Detector) and Shut-off Valve Unit

The flame eye detects the existence of a flame formed by normal combustion.

This function is essential for safe operation because the continuous fuel supply to the combustion chamber during absence of flame can cause an explosion at the time of the following ignition. Installation rates for the flame eye and the shut-off valve unit reached on average about 85% and 88%, respectively.

e. Air Pressure Sensor, Pressure Gauge after Regulator, Oil Pressure Gauge, Gas Pressure Gauges (after Shut-off Valve and at Burner Inlet)

Installation rates of the above devices were 61%, 74%, 77%, 98% and 98%, respectively. Air pressure sensor and pressure gauge after regulator for oil-fired boiler show noticeably low installation rates. In particular, the installation rate was worst for diesel-fired boilers : only 27% for the air pressure sensor and 36% for the pressure gauge after regulator. Oil and gas pressure gauges were installed at relatively high rates.

f. Oil Temperature Gauge

The installation rate of this device was still low at 50% on average.

g. Atomizing Steam Pressure Gauge

The installation rate of the atomizing steam pressure gauge was still low at 61% on average.

h. Gas Pressure Limits Switch

This device works as a detector of gas pressure and conveys a signal to the shut-off valve unit in case the pressure exceeds the lower or upper limit. The installation rate of the gas pressure limits switch reached 86%. However, due to its vital function, further promotion of installation is still required.

2) Ages of Boilers in ZMCM

Boilers in ZMCM are generally old, and the average is found to be 20 years old by the questionnaire survey. The age class with the largest number of boilers is 20-30 years (built between 1964 to 1973) with a share of 35%.

3) Progress in Emission Control and Energy Saving

The conditions of combustion facilities in view of NOx emission reduction and energy saving as compared to the conditions at the time of the previous JICA study are as follows:

a.	No improvement was made:	1 plant
b.	Improved by means of fuel change which was enforced by the supply side:	17 plants
c.	Improved by careful combustion control by the plant's initiative:	5 plants
d.	Improved by voluntary employment of control equipment such as low-NOx burners and EGR units:	16 plants
e.	Improved little in spite of employment of the control equipment:	1 plant
f.	Now ordering control equipment such as low-NOx burners and EGR units:	2 plants
g.	Already installed or now ordering energy saving equipment :	4 plants

(2) Operational Conditions of Combustion Equipment

1) Combustion Status

The operating conditions of boilers observed in ZMCM are characterized by low combustion load and high excess air. It was found that about a half of the factories surveyed during the winter season of 1993/94 were operated at a load below 60% of the rated capacity.

Average oxygen concentration of exhaust gas from various types of equipment is 5.0% or more, and that of gas-fired furnaces is the highest at about 14%. Exhaust gases of industrial furnaces tend to contain not only the combustion exhaust gas but also the air surrounding the materials processed. Therefore, it is more difficult to control the oxygen concentration of exhaust gas from the furnaces than that from boilers. The target control range of the oxygen concentration in exhaust gas is considered to be 4 ± 1 % for boilers based on experience in Japan.

2) Situation of NOx Emission

The answers for exhaust gas NOx concentrations were distributed in a range of zero ppm to more than 2,000 ppm. High NOx concentrations are possible in the cases of industrial furnaces that require very high temperature to process metals or ceramics. On the other hand, the very low concentrations such as 10 ppm or less are very hard to be realized unless the exhaust gas is diluted intentionally. Such doubtful data were reported for 16 facilities.

The NOx concentrations for several boilers were found to be exceeding the present emission standard. But, these enterprises have individual plans to cope with the high NOx concentration in exhaust gas, such as replacement of boilers with new ones, introduction of EGR (exhaust gas recirculation), and fuel switchover from oil to natural gas.

From the above observations, most small enterprises will be able to satisfy the new emission standards to be enforced from January 1998, if the same fuels are continued to be used beyond the target date.

3) Skill of Operators in Combustion Control

The Current situation regarding assignment of qualified operators was covered by the questionnaire. Out of 41 enterprises which have an obligation to assign licensed personnel to operate boilers, more than 90% of them naturally answered "Yes", and only one enterprise answered "No". Even four enterprises which have no obligation have assigned licensed personnel for their equipment operation. The regulation by STPS is considered to be generally observed by relevant companies.

(3) Summary and Discussion

1) Problem in Determining Boiler Load

The boiler load was not able to be determined for 37% of all facilities in the diagnostic survey, because there were no means to determine fuel consumption rate. Therefore, the evaluation of combustion status of these facilities concerning NOx emission was not possible.

2) Problem in Emission Standards Concerning NOx Concentration, Boiler Load and CO Concentration

In December 1994, the standard on CO emission was abolished. Consequently, in the case when the NOx concentration is somewhat higher than the emission standard value at the rated load, the plant may reduce the boiler load to 60% or less and increase the CO concentration by operation with slightly incomplete combustion at the time of the inspection by the authority. This is considered to be a problem associated with the new regulation.

3) Establishment of Measurement Certification System

At nearly all plants, and mainly small or medium size plants, measurement of pollutant concentrations in exhaust gases is entrusted to measurement companies. However, there is no certification system for measuring devices and standard gases owned by these companies. There have been a few cases wherein a factory was ordered by the government to partly suspend operations as a result of reporting erroneous measurement data from a measurement company. This indicates the necessity of early legislation for inspection and certification of measurement businesses.

4) State of Switchover to Quality Fuels

a. Switchover to Natural Gas

In the previous JICA study, about 35% of the 359 facilities owned by 97 surveyed companies were using natural gas exclusively. In the latest questionnaire survey on the 140 facilities owned by 47 factories, this ratio increased to 60%.

b. Switchover to Gas Oil and Diesel Oil

The percentage of factories using liquid fuels is now 40%, a substantial drop from the time of the previous survey when heavy oil was used in large quantity. In these factories, diesel oil is used in only eight facilities (5.7% of the total), partly because of its high price. Several plants did not change either the burner nozzle or the tip when changing fuel from heavy oil to gas oil or diesel.

5) Combustion with Inappropriate Excess Air

The questionnaire survey revealed that only 15 or 10% of 143 combustion facilities were operated with an oxygen concentration of exhaust gas at 4% or less. The majority of factories in ZMCM are operated with excessive amount of combustion air, and more effort must be directed to energy conservation.

Chapter 4 Combustion Test

4.1 Outline of the Combustion Tests

(1) Major Equipment in the Test Plant

The test boiler and major auxiliary equipment were manufactured in Japan and transported to Mexico. Specifications of the boiler are as follows :

Name	Takao FTN-30
Type	Flue and smoke-tube packaged type
Combustion method	Pressurized down flow 3-pass combustion
Rated evaporation	3.6 t/h
Rated heat output	1.94×10^6 kcal/h
Rated pressure	10 kg/cm^2
Normal pressure	7 kg/cm^2
Heat transfer area	49.6 m^2
Drum diameter	1,924 mm
Boiler length	4,500 mm (including front and rear smoke chambers)
Combustion chamber volume	2.409 m^3
Rated volumetric load of combustion chamber	926×10^3 kcal/m^3/h
Draft system	Forced draft system
Method of boiler control	Full automatic

Since the ZMCM is about 2,240 meters above the sea level, boilers designed to be used at the sea level are usually operated in ZMCM at 70% of the rated capacity. The altitude of the IMP laboratory at Pachuca City, where the combustion tests were conducted, is about 2,400 m, and is similar to that of ZMCM. The volume of air required for combustion is 1.32 times that required at the sea level. Accordingly, the draft fan for the test boiler was designed to provide 1.32 times the volume of air which can be calculated by taking into account of the total of pressure losses due to burner, boiler, etc. and further multiplied by the safety factor.

(2) Fuels Used

- Gas oil (standard N content : 720 ppm)
- Diesel oil (standard N content : 270 ppm)

Although combustion tests with natural gas were also scheduled, it was not possible to conduct them due to the delay in construction works of gas supply.

Special attention should be paid for accurate analysis of the nitrogen content in fuel, since it is part of the fundamental data required for planning methods of NOx reduction. The Study Team and IMP analyzed the nitrogen content of a standard oil sample from Japan by their respective methods. There was a large difference between the analytical values as shown below.

Standard value (ppm)	Analysis by the Study Team (ppm)	Analysis by IMP (ppm)
5,890	5,940	2,998

Note : The standard sample used in the analysis is the one which has been certified by the Japan Petroleum Institute as a standard for analysis of nitrogen in heavy oil, and has been widely used among petroleum related companies and organizations as a most reliable sample. The certificate of this sample by the Japan Petroleum Institute is included in Data Book.

For any analytical method, regular cross-checking using standard samples is necessary.

(3) Burners Used

- Normal oil burner : The burner which forms a stable flame by the combination of inner-mixing type atomizer and swirler.
- Low-NOx oil burner(1) : The burner which has the function of self-recirculation for the combustion in the reducing atmosphere.
- Low-NOx oil burner(2) : The burner which has the function of self-recirculation and two-stage combustion.
- Low-NOx oil burner(3) : The burner which has the function of two-stage combustion for reducing combustion.
- Remodeled low-NOx oil burner : The normal oil burner which was remodeled to have the function of self-recirculation.

(4) Operation Parameters for the Test

In the combustion tests, changes of the NOx concentration in exhaust gas were investigated by changing the following parameters.

1) Oxygen concentration in exhaust gas (oxygen concentration at initial smoke or CO generation, 3%, 5%, 7%)

2) Atomizing conditions (combustion temperature, nozzle angle, atomizing medium)

3) Preheating air temperature (room temperature, 80 to 100 °C, and about 150 °C)

4) Combustion chamber load (50%, 70% and 90% of the rated load, i. e. fuel load of 120 ℓ/h, 160 ℓ/h, and 200 ℓ/h)

5) Energy saving operation (with and without air preheater, economizer, continuous blow-off device for boiler water)

6) Exhaust gas recirculation (EGR)

7) Steam injection

8) Nitrogen content of gas oil

(5) Measuring Items

1) Exhaust gas measuring items

CO, CO_2, SO_2, O_2, NOx, dust, exhaust gas velocity, and exhaust gas temperature

2) Measuring items pertaining to combustion control

Oil flow rate, oil temperature, gas flow rate, gas temperature, gas pressure, steam flow rate, atomizing steam pressure, atomized oil pressure, inlet and outlet gas temperatures and feedwater temperatures of economizer, inlet and outlet temperatures of air preheater, and combustion efficiency

4.2 Results of the Combustion Test

(1) NOx Reduction Effects of Various Combustion Methods and Techniques

Effects of various combustion methods and techniques in reducing NOx concentration were tested using the normal oil burner. The results are described below.

1) Influence of atomizing medium on NOx concentration

The NOx concentration levels in combustion with steam atomization were lower than those with air atomization for both diesel oil and gas oil. In the case of diesel oil combustion at a load of 160 ℓ/h, the NOx concentration was about a half of that with air atomization when the oxygen concentration was low. The difference narrowed as the oxygen concentration increased and it was reduced to less than 10%. In the case of gas oil, the difference increased to 35 - 41% in the intermediate range of the oxygen concentration. In some cases of gas oil combustion with air atomization, the NOx emission standard of 110 ppm was exceeded.

2) Influence of oxygen concentration on NOx concentration

In steam atomization, the NOx concentration decreased as the oxygen concentration was decreased. In air atomization, however, the NOx concentration did not decrease clearly with the decrease of the oxygen concentration.

3) Influence of combustion load on NOx concentration

The difference in the NOx concentration due to combustion load was not clear, and the difference was especially small with low excess air-ratio combustion.

4) Influence of combustion air temperature on NOx concentration

The NOx concentration increased linearly as the combustion air temperature increased. It increased by 15 to 20% when the air was preheated to 136°C, as compared with that at the normal temperature. The NOx emission standard of 110 ppm was exceeded in the gas oil combustion with the air temperature of 100°C or more.

5) Influence of burner nozzle angle on NOx concentration

A test was made to find the relation between the burner nozzle angle and the NOx concentration. With a nozzle tip having a larger spray angle of 70°, the NOx concentration level was higher in the higher range of oxygen concentration. The NOx concentration level with a nozzle tip having a smaller spray angle of 50° was higher in the lower range of oxygen concentration. The NOx concentration level with a nozzle tip having a spray angle of 60° was lowest in the overall range, indicating that this nozzle tip was most suitable to the boiler.

6) Influence of exhaust gas recirculation (EGR) on NOx concentration

The NOx concentration clearly decreased in parallel with the increase of the EGR ratio as shown in Figure 4.2.1 and Table 4.2.1.

Table 4.2.1 Relation Between EGR Ratio and NOx Reduction Ratio

		EGR Volume Ratio (%)			
	Fuel	15	20	25	28
NOx Reduction Ratio (%)	Diesel oil	24	31	38	42
	Gas oil	12	16	20	22

Note : Normal burner with 160ℓ/h fuel load

A NOx reduction ratio of 42% was achieved with diesel oil, but it was 22% with gas oil. It was shown that the effect of EGR is small on the reduction of fuel NOx originating from nitrogen in fuels.

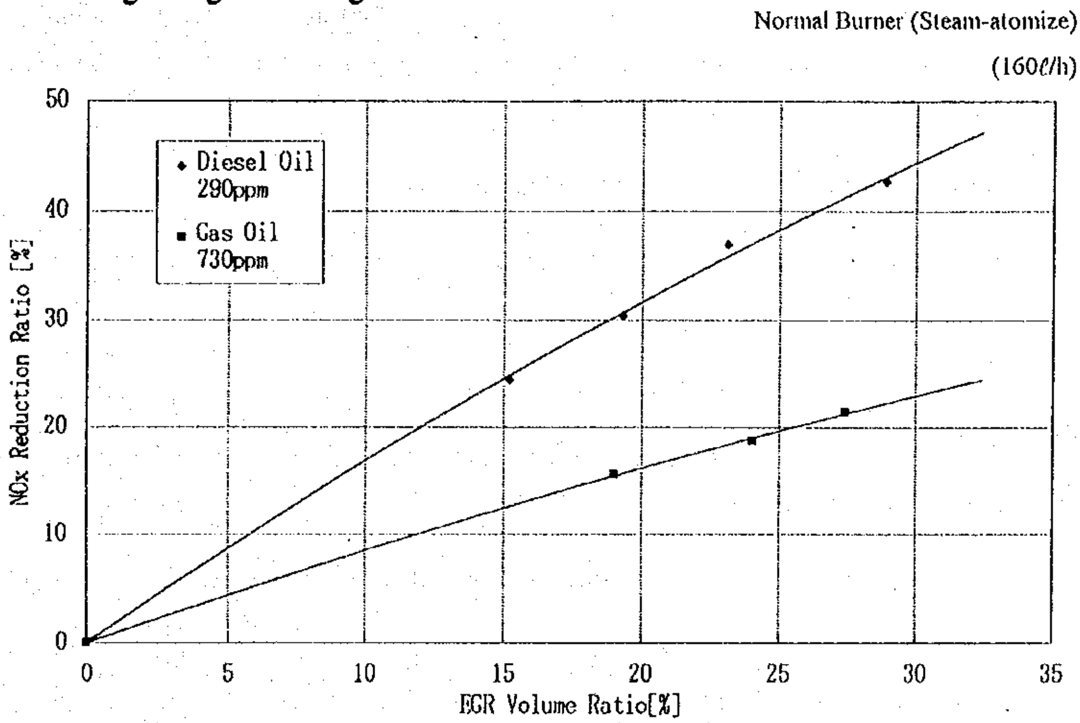


Figure 4.2.1 Effect of EGR on NOx Reduction by N Content of Fuel (Normal burner, steam atomization, fuel load 160 ℓ/h)

7) Influence of burner nozzle position on NOx concentration

When the burner nozzle was moved backward by 100mm from the appropriate position, the NOx concentration increased by about 20% as rapid and spreading combustion resulted and part of the flame contacted the burner tile.

8) Influence of mixing method on NOx concentration

NOx concentrations were compared between the inner-mixing type and the outer-mixing type, by changing the atomizing steam pressure and the oxygen concentration.

With the inner-mixing type, the NOx concentration hardly changed with the atomizing steam pressure, and it was generally below 110 ppm in the combustion of diesel oil. With the outer-mixing type, which is also widely used in ZMCM, the NOx concentration increased as the atomizing steam pressure increased, and frequently exceeded 110 ppm in the gas oil combustion when the steam pressure was above 2 kgf/cm^2.

9) Influence of atomizing steam pressure on NOx concentration

According to the diagnostic survey of factories, boilers in ZMCM are operated at considerably high atomizing steam pressure. Therefore, there is a possibility in reducing NOx generation in each boiler by setting an appropriate atomizing steam pressure.

10) Influence of steam injection on NOx concentration

In the test, the effect of the steam injection as a low-NOx technique for liquid fuels has not been confirmed.

(2) Effects of Low-NOx Burners

Table 4.2.2 shows NOx reduction effects obtained by the low-NOx burners in reference to the normal burner.

Table 4.2.2 NOx Reduction Effects of Low-NOx Burners

Type of Burner	O_2 Conc. 3 %		O_2 Conc. 5 %	
	Diesel oil	Gas oil	Diesel oil	Gas oil
Normal	60 ppm -	92 ppm -	64 ppm -	103 ppm -
Low NOx (1)	47 ppm 22 %	84 ppm 9 %	55 ppm 14 %	96 ppm 7 %
Low NOx (2)	-	75 ppm 18 %	-	83 ppm 19 %
Low NOx (3)	44 ppm 27 %	68 ppm 26 %	51 ppm 20 %	72 ppm 30 %

Note: Fuel load : 160 ℓ/h
Upper figure : NOx concentration
Lower figure : NOx reduction ratio in reference to the normal burner

The table shows that the following reductions would be possible:

Low-NOx burner (1) : 14 to 22% with diesel oil, and 7 to 9% with gas oil.
Low-NOx burner (2) : 18 to 19% with gas oil.
Low-NOx burner (3) : 20 to 27% with diesel oil, and 26 to 30% with gas oil.

The low-NOx burner (3), using the principle of two-stage combustion, showed high NOx reduction effect. All the burners including the normal burner are possible to satisfy the new NOx emission standard value of 110ppm. However, for the normal burner at a combustion load of 200 ℓ/h, care should be taken by lowering the oxygen concentration so as not to exceed the NOx emission standard.

The NOx reduction effect is further enlarged by lowering the oxygen concentration in exhaust gas as shown in Table 4.2.3. The reduction ratio was calculated in reference to the NOx concentration when the oxygen concentration in exhaust gas was 5%.

Table 4.2.2 Ratio of NOx Reduction by Lowering Oxygen Concentration (In Reference to the NOx Concentration at 5% O_2)

unit:%

Burner	Diesel Oil		Gas Oil	
	3% O_2	Limit O_2	3% O_2	Limit O_2
Normal	14	20	11	22
Low NOx (1)	13	28	10	26
Low NOx (2)	-	-	10	-
Low NOx (3)	10	16	5	9

Note : Fuel load : 160 ℓ/h

Under the fuel loads of 120 ℓ/h and 200 ℓ/h with steam atomization, the NOx concentrations were also below 110 ppm at all of the oxygen levels tested.

(3) Energy Saving Measures and Their Effects

Effects of energy saving measures are estimated for a hypothetical boiler of the size similar to that of the test boiler under the steady-state operation at a fuel load of 160 ℓ/h.

1) Effect of improving air ratio

The effects in economy and reduction of NOx resulting from decreasing the air ratio from 1.49 to 1.07 were estimated based on the result of the combustion test.
The economic effect of improving the air ratio was estimated as the saving of the fuel cost as follows :

Gas oil : 18,720 ℓ/y x US$ 0.133/ℓ = US$ 2,490 /y
Diesel oil : 18,720 ℓ/y x US$ 0.236/ℓ = US$ 4,418 /y

The effect on the reduction of NOx was estimated as follows :

Gas oil : 29.6 %
Diesel oil : 30.1 %

According to the questionnaire survey, the arithmetic mean of the exhaust gas oxygen concentration for boilers in ZMCM using liquid fuel was 6.83%. If current facilities are amenable to low air ratio combustion, it is expected to bring about considerable effect. However, the low air ratio combustion requires measuring equipment and engineers for combustion control.

2) Effect of economizer

The effect of recovering retaining heat of exhaust gas by an economizer is estimated under the following conditions :

Temperature at inlet of economizer : 236°C
Temperature at outlet of economizer : 110°C

The reduction of fuel cost is estimated as follows :

Gas oil : 30,960 ℓ/y x US$ 0.133 /ℓ = US$ 4,118 /y
Diesel oil : 40,320 ℓ/y x US$ 0.236 /ℓ= US$ 9,516 /y

Based on the reference domestic prices of Japanese made economizers (acid-and-heat-resisting glass, US$ 40,000; stainless steel, US$ 15,000), the time required to recover the facility investment is calculated to be as follows :

Material of economizer	Gas oil	Diesel oil
Glass	9.8 years	4.2 years
Stainless steel	3.7 years	1.6 years

(Above mentioned prices of economizers do not include transportation cost, customs, cost of installation, cost of piping and ducts, and interest.)

3) Effect of air heater

The heat source of the air heater installed in the test plant is the generated steam, which is an internal heat source. When the temperatures at the inlet and the outlet of the air heater are 38°C and 143°C, respectively, heat recovery is 3.8%.

On the other hand, when the heat source of the air heater is recovered heat of combustion exhaust gas, the percentage of exhaust heat recovery decreases owing to acid corrosion due to sulfur in fuel. Assuming the temperature of exhaust gas at 140°C and the temperature of preheated air at 100°C, the recovery of retaining heat of exhaust gas is 2.2%. In this case, the fuel cost saving is US$ 2,107/yr for gas oil and US$ 3,738/yr for diesel oil. Since a reference price of a Japanese made air heater is about US$ 24,000, the time required for recovering the investment is 11.4 years in the case of gas oil and 6.4 years in the case of diesel oil. Therefore, economic feasibility of this investment is low.

Although the heat of exhaust gas can be recovered by an air heater, the NOx concentration increases due to the increased temperature of the combustion air. According to the result of the combustion test, when air was preheated to 100°C, the NOx concentration increased by 10.4 % in the case of gas oil and 14.9 % in the case of diesel oil, as compared with that under the normal combustion air temperature (36 - 37 °C).

4) Effects of other energy saving measures

The boiler in the test plant was equipped with a device to recover heat from blow water. Although the main purpose of boiler water blowing is to discharge a certain volume of the boiler water to lower the concentration of impurities when the feedwater pump is operating, this device recovers heat of the drained water to preheat the feedwater. Fuel saving by this device is estimated as follows:

For gas oil :	15,840 ℓ/y and US$ 2,107/y	(2.2%)
For diesel :	15,696 ℓ/y and US$ 3,704/y	(2.2%)

As a reference price of a heat-recovery type blowing device in Japan is US$ 7,000, the period to recover the equipment cost is estimated to be 2 - 3 years.

4.3 Remodeling Normal Oil Burners

(1) Remodeling

As a result of the combustion tests, it became clear that a sufficient effect in reducing NOx can not be obtained by the exhaust gas recirculation when the nitrogen content of fuel is high, and the necessity to use low-NOx burners is high for combustion of fuels with a high content of nitrogen. However, as low-NOx burners are expensive, it is considered to be difficult financially for small-to-medium enterprises to employ low-NOx burners for their boilers. Among low-NOx burners, the self-recirculation type burners recirculate the exhaust gas to reduce combustion within the flue. This type is effective against the nitrogen in fuel, and remodeling of normal burners into this type is easy. Therefore, the burner remodeling and the combustion test were conducted.

(2) Concept of Remodeling

The normal burner was remodeled to add self-recirculation functions that allow combustion in the reducing atmosphere while maintaining the basic structure of the normal burner.

(3) Test Result and Evaluation

When gas oil (160 ℓ/h) with a nitrogen content of around 3,500 ppm was burnt with the normal burner, the NOx concentration in exhaust gas was 260 to 280 ppm at an oxygen concentration of 3%. The remodeled self-recirculation burner reduced the concentration of NOx by about 20% under the same conditions with its range from 200 ppm to 220 ppm.

This effects is comparable to that of low-NOx burners on the market. As the remodeling cost was approximately US$6,000, it is possible to recover the cost by the reduced fuel cost for 2-3 years.

However, since shapes and specifications of burners in enterprises are different, sufficient attention should be paid to remodeling to ensure the recirculation of exhaust gas for enabling the reducing combustion.

Chapter 5 Proposals on Improvement of Combustion Techniques for ZMCM

Based on the results of the investigation of stationary sources and the combustion tests as described so far, proposals will be made for the stationary sources in ZMCM, regarding the improvement of combustion techniques for NOx emission reduction and energy saving.

Section 5.1 presents proposals based on the results of the combustion tests for boilers burning liquid fuels. Section 5.2 gives suggestions concerning natural gas combustion in boilers mainly based on the existing knowledge. Section 5.3 deals with particular industrial furnaces that are also major sources of the NOx emission in ZMCM other than boilers, and proposes NOx reduction measures considered to be effective among existing methods.

5.1 Conclusions Obtained from the Results of the Combustion Test

Based on the results of the combustion tests using diesel oil and gas oil, the following are proposed for improvement of combustion techniques for ZMCM.

(1) Low-NOx Combustion Techniques

1) Boilers burning diesel oil

The results of the tests on diesel oil having a nitrogen content of 270 ppm showed that the NOx concentration in exhaust gas did not exceed the emission standard of 110 ppm with both steam atomization and air atomization. Accordingly, it is considered that no particular measures for NOx reduction are necessary for boilers burning diesel oil. However, improvement of combustion techniques is still desirable in view of reduction of the total emission of NOx and energy saving.

2) Boilers burning gas oil

The results of the tests on gas oil having a nitrogen content of 720 ppm revealed that the NOx concentration in exhaust gas would exceed the emission standard of 110 ppm under certain conditions of combustion with normal burners. The boiler and the burners used in the combustion tests were designed so that both are well balanced with each other. Moreover, the tests were conducted by skilled engineers with a boiler which was equipped with all the necessary control devices. Such conditions are considered to be not common for boilers in ZMCM. Taking into account unfavorable conditions that may be imposed on these boilers, it is natural to think that there should be the cases where introduction of certain low-NOx combustion techniques is necessary for boilers burning gas oil. Major techniques for low-NOx combustion that are judged to be effective for boilers burning gas oil based on the results of the combustion tests are as follows.

a) Introduction of steam atomization: Although it is necessary to modify existing air atomization type burners to steam atomization type, its NOx reduction effect is estimated to be large, or a maximum 30 - 40 % according to the test result.

b) Remodeling of normal burners: NOx reduction of a maximum of 20% was achieved by remodeling the normal burner so as to provide it with the function of self-recirculation of exhaust gas.

c) Low air ratio combustion: NOx concentration can be reduced by 30% by decreasing the air ratio from 1.49 to 1.07. Low-air ratio combustion is an effective measure for NOx control, but it requires equipment for combustion control.

d) Introduction of low-NOx burners: NOx reduction by 7 - 30 % was achieved in the tests of 3 types of low-NOx burners. Since the NOx reduction effect tends to increase as the air ratio decreases, careful operation with air supply control is required to maximize the effect of low-NOx burners.

e) Introduction of EGR: In the combustion tests, a maximum of 22% NOx reduction was achieved by the use of the exhaust gas recirculation device.

Among above techniques, a) introduction of steam atomization, b) remodeling of normal burners, and c) low air ratio combustion are considered to be suitable for small-to-medium size boilers since these techniques require relatively small investments. However, there are certain difficulties in adapting additional parts to existing boilers. On the other hand, d) introduction of low-NOx burners and e) introduction of EGR have higher possibilities for medium-to-large size boilers since required investments would be larger than that for the former 3 techniques. Since there would be few technical difficulties, surer effects can be expected.

(2) Operation Techniques for Energy Saving

Energy saving operation is primarily aimed at saving of fuel. However, since the fuel saving directly leads to the reduction of the exhaust gas volume, the NOx emission can be also reduced. Energy saving operation techniques such as low air ratio combustion, use of an economizer, and combustion air preheating, were studied with the test boiler. As a result, the possibilitiy of tangible effects in economy and NOx reduction were demonstrated. Since the reduction of production costs to be brought about as a result of employing these techniques is a good incentive, they should be positioned at the core of improvement of combustion techniques for ZMCM.

1) Combustion with appropriate air ratio

High air ratio combustion is a cause for emissions of NOx in high concentrations which is common in many stationary combustion facilities in ZMCM. Only a small number of combustion facilities were operated with the exhaust gas oxygen concentration at 4% or less : 15 facilities or 10% of 143 facilities surveyed by the questionnaire. These figures indicate not much improvement from the time of the previous JICA study conducted in 1990 - 1991. It is recommended to make much effort in energy saving and NOx emission reduction based on the understanding of the influence of the air ratio on the NOx concentration and the exhaust gas heat loss.

The points to be considered for adjusting the air ratio at an appropriate level are described below.

Whether or not an air ratio is appropriate can be confirmed by analyzing the oxygen concentration in the exhaust gas. For daily management, adjustments have to be made by observing the state of the flame and the smoke. Through the observation of smoke from the smokestack, the amount of air should be adjusted to a slight excess of that which generates a small amount of black smoke.

When gas oil or diesel oil is burned, the amount of air is close to being appropriate if the flame is bright with its center somewhat black. This can be observed through the front window of the boiler.

If the air amount is less than appropriate, the flame tip becomes black, and soot is generated. On the other hand, when the air is excessive, the flame becomes extremely short and branched, and vacillates violently. The color of the flame becomes light yellow.

In adjusting the air ratio, the type of fuel, loading rate, and composition of control equipment must be taken into consideration. The standard air ratio for boilers in Japan is shown in Table 5.1.1. These values are applicable for steady-state operation at the indicated loading rate.

Table 5.1.1 Standard Air Ratio for Boilers (in Japan)

Boiler Category		Loading rate (%)	Standard air ratio			
			Solid fuel	Liquid fuel	Gas fuel	Blast furnace gas and other by-produced gases
Electric power plant boilers		75 ~ 100	1.2 ~ 1.3	1.05 ~ 1.1	1.05 ~ 1.1	1.2
Other boilers	Evaporation rate more than 30 t/h	75 ~ 100	1.2 ~ 1.3	1.1 ~ 1.2	1.1 ~ 1.2	1.3
	Evaporation rate 10 to 30 t/h	75 ~ 100	-	1.2 ~ 1.3	1.2 ~ 1.3	-
	Evaporation rate less than 10 t/h	75 ~ 100	-	1.3	1.3	-

Source : Ref. D8

2) Improvement of heat transfer

As adherence of soot and scale on heat transfer surfaces greatly reduces the thermal efficiency of boilers, regular cleaning is necessary.

3) Heat recovery from exhaust gas

In boilers, it is of basic importance that the appropriate air ratio is maintained and dirt on the heat transfer surface is minimized so that the temperature of the exhaust gas does not increase. If the temperature of the exhaust gas is still high, heat from the exhaust gas should be recovered by an economizer and/or an air preheater for preheating feedwater and combustion air, for increasing the overall thermal efficiency.

4) Prevention of heat release

At many boilers in ZMCM, thermal insulation has not provided for feedwater pipes around the boiler, valves, flanges, etc. Promotion of thermal insulation is desirable.

5) Daily management

To improve energy saving for boilers, it is important to install necessary measuring equipment and to record the status of daily operation in a daily report for assessment. It is recommended that enterprises operating boilers each keep a record in the form of a graph to show long-term trends for evaporation ratio, temperature of feedwater, temperature of exhaust gas, oxygen concentration in exhaust gas etc., in order to discover abnormalities at an early stage.

5.2 Low-NOx Combustion Methods for Natural Gas

Construction work to supply natural gas to the test plant fell far behind the schedule for various reasons, and a comprehensive combustion test for natural gas could not be conducted. Therefore, technical considerations concerning natural gas combustion are described below.

(1) Methods of Low-NOx Combustion for Natural Gas

Methods of low-NOx combustion that can be considered for natural gas boilers are as follows :

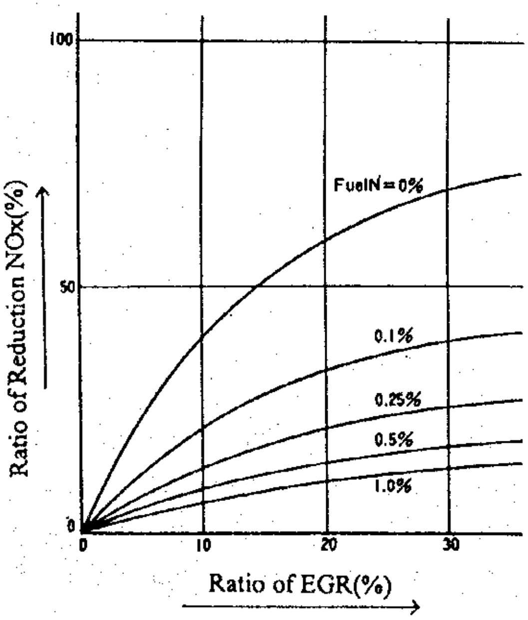
a) Improvement of function of low-NOx burners
b) Combination of various low-NOx combustion techniques using existing burners
c) Low-NOx burner plus low-NOx combustion techniques

As a low-NOx combustion technique other than low-NOx burners, exhaust gas recirculation (EGR) is considered to be most effective in natural gas combustion.

(2) Effects of EGR in Natural Gas Combustion

1) Effect of reducing NOx

As shown in Figure 5.2.1, the rate of NOx reduction using the EGR method is higher as the nitrogen content of fuel is lower. Therefore, this method is effective for the combustion of natural gas, of which the nitrogen content is low.



Source : Ref. B11

Figure 5.2.1 Effect of EGR on NOx Reduction by ERR Ratio and Nitrogen Content in Fuel

The average NOx reduction by EGR is 40% when the EGR rate is 10%, and around 60% when the EGR rate is 20%.

2) Energy saving effect and safety measure

Energy saving effect of EGR is small in comparison with the effects of other factors such as appropriate air ratio. As a safety measure, it is necessary to measure the oxygen concentration of the combustion air continually so that the concentration can be kept at 16% or more after being mixed with exhaust gas.

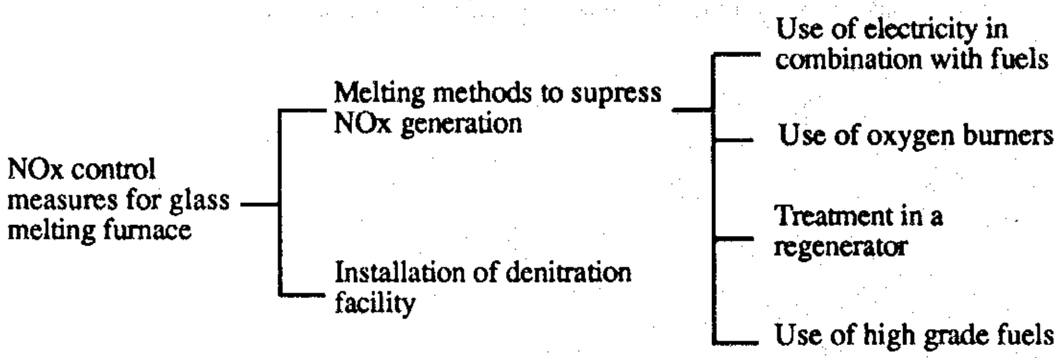
5.3 NOx Reduction Measures for Particular Industrial Furnaces

(1) Glass Melting Furnace

Factories in ZMCM that emit NOx with the highest concentration are glass factories, of which the number is also larger in comparison to other cities.

In glass melting furnaces, glass must be kept at a constant temperature of 1,500°C or more. As most low-NOx combustion methods for boilers ultimately result in lowering the flame temperature, they cannot be used for glass melting furnaces.

Almost all glass melting furnaces have a regenerator (sometimes, a heat-exchange system) for heating the secondary combustion air by using the heat of the exhaust gas in order to increase the temperature inside the furnace and to save fuel. NOx control measures generally employed in glass melting furnaces are shown below.



1) Reduction of NOx by combined use of fuel and electricity

Generally, as the use of electricity is increased, the size of the furnace can be made smaller. Therefore, the detention time of the combustion gas in the combustion chamber becomes shorter and a considerable reduction of NOx can be expected. A glass factory in ZMCM operates a facility in such a way with good results.

2) Reduction of NOx with oxygen burners

For combustion of natural gas, which does not contain nitrogen, the above-mentioned glass company developed a NOx reduction method in which oxygen is used instead of air for combustion. They have been operating production facilities employing this method since 1993.

The NOx concentration in their glass melting furnace at the time of the previous JICA study (in 1990) was 1,226 ppm (at 5% O_2). During the visit for the present study, it showed a drastic decrease to only 60 - 70 ppm. The reason for this success is that low-priced oxygen has become available through the development of a method that allows nitrogen and oxygen in the air to be easily separated by use of synthetic zeolite.

3) Reduction of NOx in regenerators

EXXON developed a non-catalytic process using NH_3 as a reducing agent. When the agent is applied to the area where the temperature is 750 - 1,000°C near the outlet of a regenerator, it is said to be possible to reduce NOx emission by 60 - 90%.

The urea spraying method sprays a 20% urea solution near the outlet of the regenerator where the temperature is around 1,000°C. It is possible to reduce NOx emission by about 40%.

(2) Rotary Cement Kilns

For rotary kilns for cement, fuel consumption per unit production has been improved and NSP kilns (neo-suspension preheater type kiln), which reduce NOx generation by improved combustion, have been developed. Also a technique combining the NSP and the non-selective contact reduction method has been developed and practically applied. For NSP kilns, a combustion chamber called a gas generator is installed in front of the suspension preheater, and NOx is removed by reducing gases such as CO and H_2 generated in the generator and the catalytic actions of the raw materials of cement. With this combination technique, a denitration rate of around 60% is obtained. As it does not require installation of large equipment, the economic burden is small.

Chapter 6 Recommendations for Dissemination of Low-NOx Combustion Techniques and Institututional Development

The characteristics of stationary sources in ZMCM have been understood as described in the previous chapters with respect to fuel used, number and specifications of equipment, and operational condition. Suitable low-NOx combustion techniques for these stationary sources were verified for different types of fuel in the combustion test conducted in Pachuca. In this chapter, necessary measures for dissemination of combustion techniques suitable for ZMCM are recommended in order to achieve compliance with the regulation for NOx emission.

In Mexico, introduction of low-NOx combustion technique is at an early stage, and the system of emission monitoring has not been completely established yet. Therefore, dissemination of low-NOx combustion techniques should be promoted in parallel with the establishment of emission monitoring systems. Since it is expected to take a considerable time to promote these two subjects, the target time of implementing recommended measures is set as January 1998 when the emission standards of NOx and other pollutants are tightened.

The aim of the recommended measures is that most stationary sources comply with the coming emission standards from the target time. Measures recommended in the following sections have mutual relations as shown in the figure below.

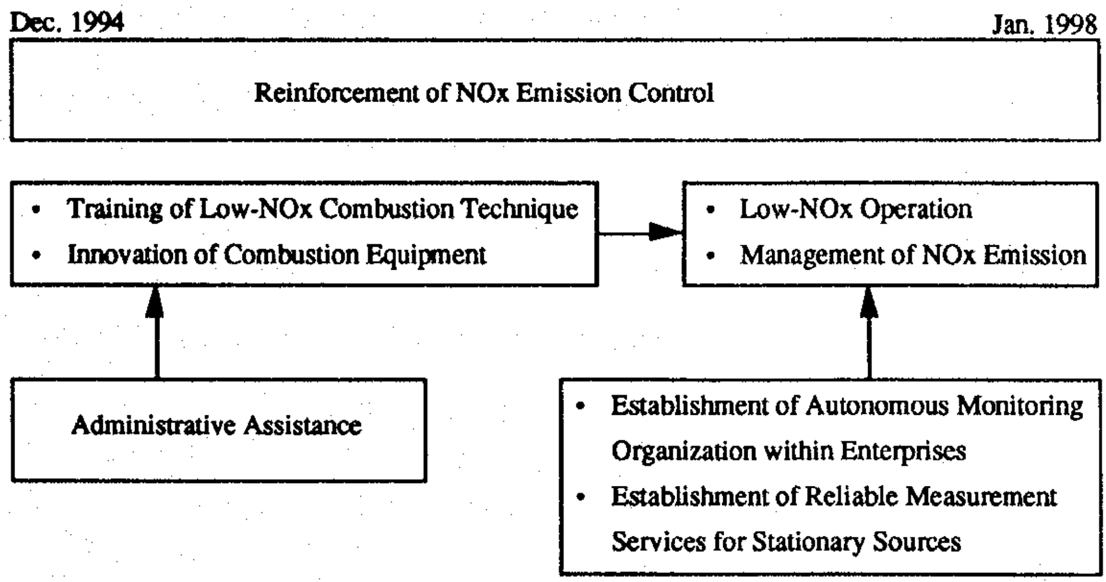


Figure Recommended Measure for Dissemination of Low-NOx combustion Techniques and Institutional Development

6.1 Development of Capability of Boiler Operators for NOx Emission Reduction

(1) Necessity of Technical Improvement

Development of the capabilities of operators in respect of safe and energy-saving operation has been established and has successfully taken root. Low-NOx and low-smoke combustion technology is also expected to be disseminated, in connection with compliance with the emission standards. The present situation regarding compliance with the standards is not satisfactory, but many enterprises are considering the adoption of control measures including fuel switchover to cleaner ones.

For these enterprises it is necessary to improve the skill of operators of combustion equipment for implementation of planned control measures. For this purpose, technical training is recommended.

The emission standards, on the other hand, have been revised. Under the new standards, the NOx emission standards for the final stage for ZMCM are prescribed as 190 ppm for boilers with the capacity of 5,250 to 43,000 MJ / hr (approximately 2.4 to 19 ton / hr), and as 110 ppm for boilers larger than 43,000 MJ / hr (approximately > 19 ton / hr).

The value of 190 ppm is not considered to be difficult for those boiler owners using gas, diesel oil and gas oil to comply with. However, it is not certain that they will be able to meet the standard of 110 ppm unless low-NOx combustion techniques are adopted.

Then the object combustion techniques for technical training should be those that are helpful for boilers larger than 43,000 MJ / hr in capacity and using gas or diesel oil or gas oil to meet 110 ppm of the NOx standard.

(2) Techniques to be Introduced

The main subjects to be learned in the training are suggested to be the following four items:

a. Mechanism of NOx and smoke generation through combustion
b. Principles of pollutants reduction and their application
c. Operation methods that reduce pollutants (including practical exercise)
d. Energy saving operation

The operation method common to boilers with different kinds of fuel is the low air ratio combustion. The effect of the low air ratio combustion in the NOx reduction can be directly experienced in the implementation of the course. Visible differences of flames caused by air ratio should also be presented.

(3) Initial Stage of Capacity Development

The technology transfer seminar conducted in the present Study can be considered as an initial stage of technical training for the development of the capability of boiler operators. The seminar focused on the knowledge of NOx reduction and the operational techniques related to boiler operation. These subjects were learned effectively in a combination of lecture and supervised practice.

The selection of participant enterprises was undertaken by INE and persons to attend the course were selected from among the plant master (Jefe de planta), engineers, operators and management staff by the participant enterprises. Participants were classified into three fuel groups: gas, diesel oil and gas oil. Each group was given different practice program. 76 participants were dispatched from 21 private enterprises and 9 government organizations, and each participant was jointly awarded a certificate by INE and JICA for the completion of the course.

(4) Subsequent Stage of Capacity Development

Capacity development for low-NOx and low-smoke combustion techniques is particularly required for those persons engaged in boiler operation. Thus the participants in the training course are proposed to be those who are engaged in operation of boilers larger than 43,000 MJ/hr or employed by medium to large enterprises in ZMCM, in view of efficiency of total reduction. In this plan, the number of potential trainees is estimated at about 1,500 people by assuming each enterprise dispatches one person to attend the training course.

The duration of one unit of the course consisting of lectures and practice is estimated at 0.5 week with about ten attendants, so that it will take 75 weeks to complete the training of the whole expected participants from the enterprises. This implies that it is possible to finish most of the planned training of boiler operators by the scheduled time of enforcement of the new emission standards, January 1, 1998, if the training is started promptly and conducted continually.

The training is proposed to be executed by INE in cooperation with relevant government authorities. The other authorities related to the regulation of stationary sources are expected to contribute to the training in their respective fields of responsibility. A practical form of contribution to the training course would be to undertake a part of lectures and the practice of technical aspects, and to provide necessary facilities, fuels and other materials for the course.

6.2 Reinforcement of Institutional Aspects for NOx Control

(1) Assistance to Enterprises for Introduction of Low-NOx Combustion Technique

Low-NOx combustion techniques for boilers have not been disseminated enough yet in Mexico because these techniques require broad knowledge of facilities and experience in operation for adoption. Therefore it will be a matter of high priority of assistance for introduction of low-NOx combustion techniques to supply technical information about low-NOx combustion facilities, and to provide opportunities of training for operation of said facilities.

Assistance measures for introduction of low-NOx combustion techniques are proposed to be applied according to the stage of introduction, as described below.

1) Assistance for Investment in Facility Innovation

a. Guide to tax reduction or low-interest credit (suspended now)
b. Suggestion of possible methods of innovation (by an inter-industrial consultancy body)
c. Introduction of capable suppliers (by an inter-industrial consultancy body)
d. Support in evaluation of investment plan (by consultancy body formed inter-industrially)
e. Guide to the course of operator training or introducing unemployed capable operators (by an inter-industrial consultancy body)

2) Assistance for Operation Technique (Training, Operation Manual, Measurement)

a. Provision of the training course for operators (by INE in cooperation with relevant authorities)
b. Advise on preparation of operation manuals (by an inter-industrial consultancy body)
c. Introduction of capable measurement company (INE, SINALP)

The services related to investment in facility innovation are, due to their nature, suitable to be undertaken mainly by a voluntary consultancy body organized by private industries according to type of industry. On the other hand, assistance in development of operation technique is suitable to be undertaken by mainly governmental organizations because they have sufficient qualified experts and materials for that purpose. Necessary expenses for implementation of the assistance schemes is recommended to be shared by the government organization, inter-industry consultancy body and the beneficiary of the assistance according to a reasonable allocation.

(2) Establishment of Autonomous Monitoring Organization Within Enterprises

It is necessary for boiler owners to know the actual state of exhaust gas quality not only to maintain sound operation but to report INE of periodical operation records on designated items of the emission regulation. Acquisition of measuring devices and measurement techniques is required of boiler owners because measurement is the starting point of any kind of control.

The autonomous monitoring organization is expected to examine the exhaust gas composition as to whether or not it complies with the emission standards. The most suitable person for the post of chief of the monitoring organization is the head of a factory who represents the factory on behalf of the owners of the enterprise. Practical work of the monitoring requires experts qualified in both measuring exhaust gas composition and arranging pollution control measures. These experts can be called "pollution control engineers". Moreover, an authoritative licensing system for pollution control engineers is necessary.

In Japan the Law for the Establishment of Organizations for Pollution Control in Specified Factories was enacted in June 1971. A total of about 20,000 specified factories had registered with the government about 40,000 licensed pollution control engineers as the chiefs of autonomous monitoring organizations as of March, 1993. Besides registered pollution control engineers, about 430,000 persons have been licensed and engaged in pollution control as members of the autonomous monitoring organization belonging to the factories. Owing to the efforts of industrial sectors, no lawsuit against the violation of the Law for Prevention of Air Pollution has been brought in the past several years.

(3) Establishment of Reliable Measurement Services for Stationary Sources

An autonomous monitoring organization, discussed in the preceding section, is expected to be established at each plant where it is required, but it will take a certain time for dissemination and furthermore difficulty should be anticipated in introducing this organization to all the enterprises including small sized factories. Therefore, adoption of the practice of commissioning measurement of exhaust gas will be a practical way to compensate for the absence of the essential function of the autonomous monitoring organization.

Each enterprise needs to be aware of the situation of its NOx emission continuously in order to meet PROFEPA's standards. The suitable way of self monitoring for medium-to-small enterprises is to entrust it to external professional persons, at the enterprise's expense.

However, such entrustment cannot be expected to be reliable unless the qualifications of measurement companies reaches a satisfactory level verified by the authority. In this respect, the level of measurement services can not be said as satisfactory at present. Therefore a reliable measurement service system should be established by developing the indispensable system components as described below.

1) Official Verification System of Measuring Instruments

The emission standards prescribe the methods to determine the concentration of the regulated substances. However, requirements for measuring devices are not explicitly stated. Namely, no explicit definitions of devices to be utilized are given. To establish an authorized calibration system, which is necessary for reliable measurement service, the following components are required:

a. Responsible authority and its local branches
b. Designated measuring equipment to be verified
c. Verification method and permissible deviation are to be published
d. Eeffective duration of the verification and indication of the verified status are to be made known
e. Restriction of usage of unverified instruments in business activities prescribed by related legislation

2) System of Supplying Standard Substances for Measurement

One of the essential elements to secure the reliability of measurement is traceability which is defined as "a nature that a result of measurement, in general, has the comparability through a chain in sequence to a proper standard, international standard or national". The traceability can be realized by establishment of the supply system for measurement standards throughout the country. The supply system of standard substances is the subject to be completed as soon as possible in Mexico.

Though it is ideal that the standard substances are supplied by the national supreme calibration organization (the National Metrology Center in Mexico: CENAM), but this is very difficult due to CENAM's insufficient capacity to answer the whole demand of standard substances in the country. Therefore, the function of the national supreme calibration organization is to be partly transferred to another subordinate organization for valuation of standard substances without sacrificing accuracy and reliability. Such a hierarchical structure of authorized calibration organization is thought to be the basis of building the traceability of measurements in the country.

3) License System for Companies and Persons Engaged in Measurement Service

The Law on Metrology and Normalization prescribes two kinds of authorized bodies that are to conduct accurate and impartial measurement for other persons (licensed laboratory and verification unit). However, the accreditation by SECOFI and the registration by INE for the inspection of exhaust gas are not linked to each other at present. The number of bodies accredited as a test laboratory or verificatión unit in the field of environment is still small and not enough to meet the demand of measurement under the jurisdiction of INE.

Therefore, it is proposed to increase the number of accredited bodies in the related field to INE and to have the registration system of INE for measurement company linked to the accredited system of SECOFI.

Another proposal for the licensing system of measurement companies is to create a special qualification system for the chief engineer who is responsible for the measurement activities in technical aspects. It is proposed that every company which intends to undertake the measurement services be obliged to assign a licensed engineer with enough ability as the chief of the measurement group.

Chapter 7 Conclusions and Recommendations

7.1 Combustion Technology

Based on the results of the combustion test, investigation of the stationary sources in ZMCM, and the existing knowledge, the following are recommended for improving the current situation of air pollutant emissions and energy consumption in the stationary sources in ZMCM.

(1) Low air ratio

The majority of combustion facilities in ZMCM are operated with an excessive amount of combustion air. The air ratio should be kept at an appropriate level in order to reduce the amount of NOx emission and promote fuel saving.

(2) Boilers burning diesel oil

For boilers burning diesel oil, it is considered that no particular NOx reduction measures are necessary to meet the new standards for NOx emission applicable from 1998 if the boilers are operated in the proper manner. However, improvements of combustion techniques are still desirable in view of reducing the total emission of NOx and saving fuel consumption. Introduction of self-recirculation type low-NOx burners and exhaust gas recirculation (EGR) is desirable.

(3) Boilers burning gas oil

For boilers burning gas oil using normal burners, it was found that the exhaust gas NOx concentration might exceed the new NOx emission standards depending on operational conditions.

For relatively large boilers, introduction of low-NOx burners and EGR is most desirable. Although required investments for these measures would be relatively large, reliable effects are expected since operational difficulties in these measures are small.

For relatively small boilers in small-to-medium enterprises, recommended measures are: 1) introduction of steam atomization of fuel instead of air atomization, 2) remodeling of existing burners into the type of self-recirculation of exhaust gas, and 3) combustion with low air ratio (this is common to all kinds of boilers). These measures bring about considerable effects and do not require large amount of investment. However, adaptation of additional components to existing boilers should be done with due cares.

(4) Boilers burning natural gas

There are no particular problems for boilers burning natural gas to meet the new emission standards. However, in view of reducing the total emission of NOx in ZMCM, it is desirable to make efforts at all air pollution sources. It is recommended to employ self-recirculation type low-NOx burners and EGR, since recirculation of exhaust gas is most effective in reducing NOx emission for fuels of low nitrogen content such as natural gas.

(5) Energy saving

Promotion of energy saving brings about not only economic effects but also reduction of pollutant emissions when appropriate measures are taken. Among them, combustion with low excess air is the fundamental step. In addition, promotion of various measures for recovering heat from exhaust gas and blow water, prevention of heat loss from heat transfer surfaces, and minimization of radiation heat loss is recommended.

(6) Control devices for combustion and safety

Installation of measuring and control devices for boiler combustion operation and safety assurance is found to be insufficient in ZMCM. The situation is similar to that in 1990 - 1991 when the previous JICA study was conducted. Promotion of installing such devices is strongly recommended, since they are basic tools for the proper operation.

(7) Particular industrial furnaces

Other than boilers, glass melting furnaces and rotary cement kilns are also significant stationary air pollution sources in ZMCM. The NOx concentrations of exhaust gases from these furnaces are very high since they are operated at high temperature. For these industries, new technologies for reduction of pollutant emissions are available, and promotion of employing these technologies are recommended.

7.2 Supporting Measures for Implementation

For dissemination of combustion technologies recommended above, appropriate institutional supports are necessary. The following are recommended as supportive measures for implementation of physical measures.

(1) Capacity development of operators

Development of capacity of personnel engaged in operation of combustion facilities is necessary to apply the recommended technologies. For this purpose, a training program consisting of lectures and practices should be developed and implemented through the cooperation of governmental and private organizations concerned. The combustion test plant installed for the present Study could be effectively utilized in the training program.

(2) Measures to support investment and operation

Supportive measures for enterprises are necessary for improvement of combustion facilities and their operation in both the stages of facility investment and facility operation.

The following are recommended for the investment stage:

- tax reduction or low interest credit
- consultation on possible methods of facility improvement
- introducing capable suppliers
- support of evaluating investment plans
- guide to operator training programs or introducing capable operators

The following are recommended for the stage of facility operation:

- implementation of the training program
- advice on preparation of operation manuals
- introducing capable companies for exhaust gas measurement

(3) Autonomous monitoring organization in enterprises

Establishment of a self-monitoring organization is recommended in each enterprise having pollutant emitting facilities subjected to the government emission regulation. This organization conducts measurements of pollutant concentrations of exhaust gas as well as other parameters necessary for operation of the facilities, and plans necessary improvements for them. Since smaller enterprises have difficulties in conducting the exhaust gas measurements, the measurements can be entrusted to the professional companies of a satisfactory quality certified by the authority, except for the parameters necessary for the daily operation.

(4) Establishment of reliable measurement services

As stated above, reliable measurement companies must be made available for many enterprises. The current situation of such services is considered to be not totally satisfactory. The current legal system for the measurement of pollution related parameters should be strengthened in terms of the following components:

- certification system of measurement companies and individuals
- certification system of measuring equipment
- certification system of standard substances for measurements

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