of INE is self-explanatory by its organization consisting of six general directorates or equivalents as shown below:

Advisory Staff on Juridical Affairs (Asesoría de Asuntos Jurídicos)
Administration Unit
G.D. of Investigation and Technological Development
G.D. of Utilization of Natural Resources
G.D. of Environmental Standardization
G.D. of Ecological Planning

General Directorate of Environmental Standardization is the leading Mexican body in the Steering Committee of the current Study.

PROFEPA is responsible for environmental inspection, and it controls activities that endanger the environmental conditions by violating the relevant regulations. As a part of its duties, "environmental conservation agreements" have been concluded with respective industries, and some companies were punished by having to suspend their operations because of non-compliance with the agreements.

2.4.2 Pollutant Emission Standards for Stationary Sources

(1) Emission Standards for Boilers and Other Combustion Equipment

"Permissible Maximum Emission Level of Smoke, Particulates, $SO_2$ and NOx, from the Equipment for Indirect Heating Combustion and Operational Condition, and Permissible Maximum Emission Level of SO2 from the Equipment of Direct Heating Combustion with Solid, Liquid or Gaseous Fossil Fuel or their combination" was announced on December 2, 1994 in the official gazette (Ref. B3), and was brought into force on the next day. The preceding emission standards issued November 18, 1993 (Ref. B6) were accordingly replaced by the new standards. The contents of the preceding and new standards are shown in Data Book. Essential aspects of the revision of emission standards for ZMCM are summarized below.

1) Smoke Regulation for ZMCM

Smoke regulation for small boilers was made tighter from December 1994, and will be tightened again from January 1998.

| Capacity (MJ/hr) | Fuel type | Blot number | | |
|---|---|---|---|---|
| | | Previous | Until Dec.1997 | From Jan.1998 |
| up to 5,250 | heavy oil, gasoil | 6 | 4 | 3 |
| | other liquid | 5 | 3 | 2 |
| | gas | NA | 0 | 0 |
| 5,251~43,000 | liquid | NA | NA | NA |
| | gas | NA | NA | NA |
| 43,001~110,000 | liquid | NA | NA | NA |
| | gas | NA | NA | NA |
| above 110,000 | liquid | NA | NA | NA |
| | gas | NA | NA | NA |

NA: Not applicable

2) Air Ratio Regulation for ZMCM

Air ratio regulation was adopted from December 1994, and will be tightened from January 1998.

| Capacity (MJ/hr) | Volume ratio in % | | |
|---|---|---|---|
| | Previous | Until Dec.1997 | From Jan.1998 |
| up to 5,250 | NA | 60 | 50 |
| 5,251~43,000 | NA | 50 | 40 |
| 43,001~110,000 | NA | 40 | 30 |
| above 110,000 | NA | 30 | 25 |

NA: Not applicable

3) Total Suspended Particulates (TSP) Regulation for ZMCM

The standards for medium-size boilers with the capacity of 43,000 to 110,000 MJ/hr applicable until the end of 1997 were loosened, but the standards will be evntually tightened by 13% from the previous level. As for those with the capacity of 5,251 to 43,000 MJ/hr or above 110,000 MJ/hr, the standards will stay at the previous level until December 1997, and then will be tightened by 13 to 25% from the start of 1998.

A regulation on the equipment burning solid fuel was newly introduced in December 1994, and will be tightened from January 1998.

| Capacity (MJ/hr) | Fuel type | Concentration in $mg/m^3$ | | |
|---|---|---|---|---|
| | | 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 | 100 | 100 | 75 |
| | gas | NA | NA | NA |
| 43,001~110,000 | liquid | 70 | 100 | 60 |
| | gas | NA | NA | NA |
| above 110,000 | solid | NA | 70 | 60 |
| | liquid | 70 | 70 | 60 |
| | gas | NA | NA | NA |

NA: Not applicable

4) $SO_2$ Regulation for ZMCM

The standards for large-size equipment with the capacity above 43,000 MJ/hr are to be loosened until the end of 1997, but will be subsequently tightened by 31 to 45%. For those with the capacity of 5,251 to 43,000 MJ/hr, the standards will stay unchanged until December 1997, then will be tightened by 50% from the next month. For those with the capacity up to 5,250 MJ/hr, standards were newly introduced and will be tightened by 50% from January 1998. Regulation on the equipment fired with solid fuels was newly introduced in December 1994, and will be tightened from January 1998.

| Capacity (MJ/hr) | Fuel type | Concentration in volume ppm | | |
|---|---|---|---|---|
| | | Previous | Until Dec.1997 | From Jan.1998 |
| up to 5,250 | heavy oil, gasoil | NA | 1,100 | 550 |
| | other liquid | NA | 1,100 | 550 |
| | gas | NA | NA | NA |
| 5,251~43,000 | liquid | 1,100 | 1,100 | 550 |
| | gas | NA | NA | NA |
| 43,001~110,000 | liquid | 1,000 | 1,100 | 550 |
| | gas | NA | NA | NA |
| above 110,000 | solid | NA | 1,100 | 550 |
| | liquid | 800 | 1,100 | 550 |
| | gas | NA | NA | NA |

NA: Not applicable

5) NOx Regulation for ZMCM

The NOx standards were loosened through December 1997, and thereafter will be tightened for those with the capacity above 43,000 MJ/hr except gas-fired equipment above 110,000 MJ/hr. However, for those with the capacity of 5,251 to 43,000 MJ/hr and gas-fired equipment with the capacity above 110,000 MJ/hr, standards looser than the previous ones will be applied from January 1998. The regulation on the equipment burning solid fuel was introduced in December 1994, and will be tightened from January 1998.

| Capacity (MJ/hr) | Fuel type | Concentration in volume 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

6) CO Regulation for ZMCM

The CO emission regulation was abolished in December 1994.

(2) Emission Standards for Other Stationary Sources

Emission standards for specific stationary sources are now being revised: the drafts of new standards were published in the official gazette dated June 23, 1993 (Ref. B5). The contents of the drafts are shown in Data Book. The drafts will be finalized and put into force through the due process of legislation. They stipulate permissible levels of emission by the types of industry for the following sources and pollutants :

(a) $SO_2$, $SO_3$ and sulfuric acid mist at sulfuric acid factory
(b) Dust at cement factory
(c) Dust, hydrocarbon, $SO_2$ and NOx at coal-fired power plant
(d) Dust from stationary sources other than specially designated facilities

(e) $SO_2$, $SO_3$ and sulfuric acid mist at dodecilbenzenesulfonic acid factory

(3) NOx Emission Standards for Glass Factories (Draft)

A draft of emission standards for glass factories was announced on December 2, 1994 as NOM-097-ECOL-1994 (Ref. B8). The draft intends to regulate the emissions of particulate matter and NOx from the glass production process. The standards are provided by types of product and technology and the time of application as indicated below.

(a) For Existing Furnaces in ZMCM

| Products | Technology | NOx (kg per product ton) | | | |
|---|---|---|---|---|---|
| | | Preparation period | First period | Second period | Third period |
| Vessel | Regenerative | 10.0 | 4.0 | 3.4 | 2.0 |
| | | 10.0 | 7.2 | 6.0 | 3.6 |
| | Recuperative | 10.0 | 2.5 | 2.1 | 2.0 |
| Plate | Regenerative color | 13.0 | 10.8 | 9.0 | 6.5 |
| | Regenerative clear | 13.0 | 7.8 | 6.5 | 5.5 |
| Crystal, opaline, lead glass | U.Melter | 11.0 | 4.8 | 4.0 | 2.4 |
| | Regenerative | 11.0 | 7.2 | 6.0 | 3.0 |
| Boronic silicate | Regenerative | 35.0 | 15.0 | 10.0 | 5.0 |
| Fiber | Whatever | 10.0 | 8.0 | 7.0 | 4.0 |

Note: First period : 18 weeks after the start of the regulation
Second period : 48 weeks after the start of the regulation
Third period : 120 weeks after the start of the regulation

(b) For New Furnaces or Those Undergone Major Modification in ZMCM

| Products | Technology | NOx (kg per product ton) | |
|---|---|---|---|
| | | Preparation period | Under regulation |
| Vessel | all | 10.0 | 4.0 |
| Plate | color | 13.0 | 10.8 |
| | clear | 13.0 | 7.8 |
| Crystal, opaline, lead glass | all | 11.0 | 4.8 |
| Boronic silicate | all | 35.0 | 15.0 |
| Fiber | all | 10.0 | 8.0 |

(4) Fuel Quality Standards

On the same day as the issuance of the new emission standards for combustion equipment, the quality standards of liquid and gaseous fossil fuels were announced to protect ambient air quality as NOM-086-ECOL-1994 (Ref. B7). The standard values of sulfur content in fuels for industrial use are prescribed as summarized below:

Standard Content of Total Sulfur in Fuel for Industrial Use

| Type of fuel | Maximum sulfur content |
|---|---|
| Industrial diesel | 0.5 % wt. |
| Industrial gas oil | 2.0 % wt. |
| Heavy oil (heavy type) | 4.0 % wt. |
| Natural gas | 0.32 $dm^3/m^3$ |
| LP gas | 0.140 kg/ton |

Note: 1) Gas oil will be available in ZMCM until the end of 1997.
2) The maximum sulfur content of the hydro-desulfurized heavy oil to be supplied in ZMCM from 1998 is 1%.

## 2.5 General Situation of Stationary Air Pollution Sources

Annual amounts of air pollutant emissions in ZMCM reported in the literature are shown in Table 2.5.1.

Table 2.5.1 Annual Amount of Air Pollutant Emission by Source Category

| Pollutant | Amount (ton/yr) | Mobile sources (%) | Stationary source (%) |
|---|---|---|---|
| $SO_2$ | 205,594 | 22 | 78 |
| NOx | 177,339 | 76 | 24 |
| Particulates | 26,959 | 35 | 65 |
| HC | 372,525 | 81 | 19 |
| CO | 2,923,265 | 98 | 2 |

Source: Ref. A2. (The data year is considered to be 1989)

Similar figures are reported in the PICCA report (Ref. A1) as the data for 1989. Stationary sources show large shares in emissions of $SO_2$ and particulates and a considerable share in emission of NOx.

However, it is considered that the amounts of pollutant emissions shown above have been reduced to some extent by the present time. Especially, the emission of $SO_2$ must have been decreased considerably in the past several years resulting from significant measures taken by the authorities including the replacement of high-sulfur heavy oil with natural gas, gasoil and diesel in stationary sources, the closure of an old oil refinery, and reduction of sulfur content of diesel oil for mobile and stationary sources. Such reductions of $SO_2$ emissions have been reflected in the decrease of the ambient concentration of $SO_2$ in the recent years as described in Section 2.3.3.

In spite of the above fact, stationary sources remain as a significant contributor to the emissions of $SO_2$, particulates, and NOx.

As stationary sources in ZMCM, there are two thermoelectric power plants and a large number of manufacturing industries and service facilities. The thermoelectric power plants use only natural gas as fuel at present.

The total number of manufacturing companies 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 number in each of the wards and cities is shown in Table 2.5.2. The number according to scale is shown in Table 2.5.3.

Table 2.5.2 Number of Manufacturing Companies by Wards and Cities in ZMCM (1988)

| | | Wards and Cities | Total | Large | % of land used for industries |
|---|---|---|---|---|---|
| DF | 1 | ALVARO OBREGON | 920 | 6 | 15.0 |
| | 2 | AZAPOTZALCO | 1,656 | 64 | 24.7 |
| | 3 | BENITO JUAREZ | 1,764 | 25 | 2.9 |
| | 4 | COYOACAN | 798 | 26 | 1.8 |
| | 5 | CUAJIMALPA | 171 | 2 | 0.0 |
| | 6 | CUAUHTEMOC | 4,383 | 35 | 3.8 |
| | 7 | GUSTAVO A. MADERO | 2,809 | 26 | 28.0 |
| | 8 | IZTACALCO | 1,419 | 26 | 11.5 |
| | 9 | IZTAPALAPA | 3,149 | 46 | 6.0 |
| | 10 | MAGDALENA CONTRERAS | 167 | 0 | 0.4 |
| | 11 | MIGUEL HIDALGO | 1,368 | 33 | 7.9 |
| | 12 | MILPA ALTA | 123 | 0 | 0.6 |
| | 13 | TLAHUAC | 458 | 3 | 1.4 |
| | 14 | TLALPAN | 489 | 15 | 1.7 |
| | 15 | VENUSTIANO CARRANZA | 1,749 | 11 | 3.0 |
| | 16 | XOCHIMILCO | 401 | 8 | 1.9 |
| | | DF Total | 21,824 | 326 | |
| MCEM | 17 | ATIZAPAN DE ZARAGOZA | 337 | 13 | 1.0 |
| | 18 | COACALCO | 76 | 6 | 1.0 |
| | 19 | CUAUTITLAN | 80 | 3 | 2.4 |
| | 20 | CUAUTITLAN IZCALLI | 170 | 9 | 5.1 |
| | 21 | CHALCO | 92 | 1 | 0.5 |
| | 22 | CHICOLOAPAN | 119 | 0 | 1.0 |
| | 23 | CHIMALHUACAN | 80 | 0 | 1.0 |
| | 24 | ECATEPEC | 1,378 | 34 | 12.2 |
| | 25 | HUIXQUILUCAN | 40 | 0 | 5.0 |
| | 26 | IXTAPALUCA | 182 | 2 | 1.0 |
| | 27 | LA PAZ | 205 | 0 | 1.0 |
| | 28 | NAUCALPAN DE JUAREZ | 1,888 | 196 | 4.8 |
| | 29 | NEZAHUALCOYOTL | 1,573 | 2 | 0.4 |
| | 30 | NICOLAS REMERO | 113 | 0 | 1.0 |
| | 31 | TECAMAC | 62 | 1 | 1.0 |
| | 32 | TLALNEPANTLA | 1,648 | 106 | 15.8 |
| | 33 | TULTITLAN | 257 | 23 | 8.7 |
| | | MCEM Total | 8,300 | 405 | |
| ZMCM | | ZMCM Total | 30,124 | 731 | |

Source: Ref. A2.

Table 2.5.3 Number of Manufacturing Companies in ZMCM by Size Categories (1988)

| Size Category | Number of Manufacturing Companies | | | 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 |

Source: Ref. A2.
Note: Size of companies is classified according to the number of employees as follows:

Large: 251 or more
Medium: 101 to 250
Small: 16 to 100
Micro: 15 or less

The number of service facilities in ZMCM by types of services are shown in Table 2.5.4.

Table 2.5.4 Number of Service Facilities in ZMCM (1988)

| Type of Service Facility | DF | MCEM | ZMCM Total |
|---|---|---|---|
| Restaurants | 425 | 170 | 595 |
| Public baths | 245 | 53 | 298 |
| Sport centers | 75 | 16 | 91 |
| Hospitals | 20 | 20 | 40 |
| Hotels | 456 | 34 | 490 |
| Bakeries | 802 | 366 | 1,168 |
| Laundromats and dry cleaning shops | 1,888 | 622 | 2,510 |
| Mills and tortillerias | 5,211 | 2,141 | 7,352 |
| Total | 9,122 | 3,422 | 12,544 |

Source: Ref. B1.

## 2.6 Inspection of Air Pollutant Emissions From Stationary Sources

### 2.6.1 Results of Official Monitoring

The Industry Verification Program in México Valley was started in July 1992. This program measures air pollutant emissions at all industries located in ZMCM once a year, and requires industries to report the result of measurement to the competent authority, General Directorate of Environmental Standardization (Dirección General de Normatitividad Ambiental) of INE. This program was based on the General Law of Ecological Balance and Environmental Protection and its subordinate Regulation of the Prevention and Control of Atmospheric Pollution.

The first step of this program is to require industries submit to INE a report, which includes such data as magnitude of pollutant emission, information on installed control equipment, and fuel consumption.

As the second step, PROFEPA executes inspections of industrial facilities. These inspections are made to confirm if the submitted emissions report is satisfactory, and if the reported data are true. In case important offenses are found, the enterprises can be ordered to partially or fully suspend operation. In case of minor offenses, technical recommendations are given, with which the enterprise should comply promptly.

During the period from August 1992 to July 1993, PROFEPA completed a total of 8,363 effective inspections under the Industry Verification Program. This number of enterprises is only 28% of the total in ZMCM. However, since the numbers of large and medium enterprises inspected were 836 and 1,004, respectively, most of the significant stationary pollution sources in ZMCM are considered to have been covered as shown in Table 2.6.1.

Table 2.6.1 Number of Inspected Industries by PROFEPA During the Period from August 1992 to July 1993

| Size of enterprise | Total number of enterprises in ZMCM | Number of enterprises inspected | Ratio of inspected enterprises |
|---|---|---|---|
| Large | 731 | 836 | 100% |
| Medium | 802 | 1,004 | 100% |
| Small | 5,994 | 3,680 | 61% |
| Micro | 22,595 | 2,843 | 13% |
| Total | 30,122 | 8,363 | 28% |

Source : PROFEPA (except for the total number of enterprises)
The total number of enterprises is for 1988 (Ref. A2).

As a result of above inspections, sanctions were taken at 542 enterprises (6%) against important offenses, and 6,598 enterprises (79%) were found to have lighter offenses and were given technical recommendations. The enterprises that were found to have no problem was no more than 1,088 (13%). This number of ratio of emission standards offenses includes not only cases of NOx emission but also those of smoke, SOx, and CO emissions as well as hazardous waste; therefore, the actual offenses for NOx emissions would be less than indicated above.

### 2.6.2 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 (hereinafter called "consultant") because most medium and small enterprises do not have measuring equipment and staff qualified for measurement work. Even when an enterprise has measuring equipment in its plant, the measurement is entrusted to a consultant in order to secure the objectivity of the data reported. Consultants who provide this service are required to register with the INE.

However, even among registered consultants, many do not have their measuring devices authorized or do not have standard gases to calibrate the devices. It sometimes happens that an enterprise is identified as offending against the emission standards by mistake due to erroneous measurement by the consultant. The severer the enforcement of the regulation, the more accurate and reliable measurement of pollutant emission it requires so that the impartiality of the regulation can be preserved. That is why early legislation is needed for establishment of an inspection and certification system applicable to measurement consultants, measuring devices and standard gases, and for establishment of qualification system of measurement technicians.

### 2.6.3 Qualification of Measurement Service Companies

(1) General Regulation on Monitoring Activity

All measurements done for commercial and service transactions and related to industrial processes, scientific research and technological developments are fundamentally regulated by the Federal Law on Metrology and Standardization and its subordinate ordinances. The law, enacted on January 26, 1988, aims at realizing uniformity and reliability of measurement by establishing a national calibration system.

According to the law, the duty of the state is to maintain the standards of basic units and derivative units for measurement, and to control the instruments, methods and capability of laboratories for measuring services; the procedure of authorization of laboratories and the requirements to be satisfied for the authorization is prescribed concretely in the law and its subordinates.

The basic concept of the law is that the major part of official measurements should be undertaken by the authorized laboratories, and the government achieves the uniformity and reliability of measurement indirectly by controlling the quality of the measurement work of the authorized laboratories and the quality of the laboratories themselves.

Authorized laboratories, called testing laboratories, are selected in accordance with the general criteria for the operation of testing laboratories which is managed by SINALP. An applicant laboratory is examined regarding management organization, equipment and materials, capability of staff, operating manuals and other related matters necessary for the execution of reliable measurement. The examinations are made by an appraisal committee which is organized by SECOFI in each of relevant categories of industry. As of February 1994, the appraisal committee was organized for the following seven categories of industry. The number of laboratories authorized by that time in each industry is shown in the parentheses.

| | |
|---|---|
| Construction | (24 labs) |
| Electric and electronic | (54 labs) |
| Metal and Machinery | (49 labs) |
| Chemical | (26 labs) |
| Fiber and clothes | ( 6 labs) |
| Food | (12 labs) |
| Environmental pollution | ( 2 labs) |

There were a total of 173 testing laboratories authorized as of February 1994. However, there were only two laboratories accredited in the field of environmental pollution, and none in air pollution. The laboratory of INE was at that time applying to be the first testing laboratory in the field of air pollution.

(2) Qualified Companies for Monitoring Services

Those enterprises that must reduce discharge of pollutants are obliged to submit the results of monitoring of wastewater effluents, solid waste discharges and exhaust gas emissions to INE, DF or EDOMEX. These reports are submitted so that judgements can be made on the necessity of issuing special instructions for protection of environmental conditions.

As for the emission of air pollutants, the reports of large enterprises are processed by INE and that of smaller enterprises are processed by DF or EDOMEX. The monitoring of the air pollutant emissions is required to be conducted by those registered in INE but need not necessarily be authorized by SINALP. As a result of this requirement, 95 monitoring service companies were registered, as of February 1994, for preparing official reports concerning air pollution control of stationary sources.

Registration of monitoring service companies at INE is made according to two stages of examination: the first stage is examination of the documents that describe the capability of the applying company, and the second stage is on-the-spot inspection and evaluation of measuring skills. Measuring skill is evaluated through the practical operation of the isokinetic suction method. The necessary documents for the first stage examination are as follows:

Letter of application
The certificate of incorporation
Registered tax payer number
List of measuring equipment and copies of operation manuals
Curriculum vitae of specialized technicians
History of company

## 2.7 Capacity Development for Combustion Management

### 2.7.1 Existing Licensing System for Operators of Combustion Eequipment

As personnel resopnsible for the operation of combustion equipment, only those for boilers are legally specified, as Plant Master (Jefe de Planta), Operator (Operador) and Fireman (Fogonero) by the Regulation for Inspection on Steam Generators and High Pressure Vessels (Ref. G1). This Regulation is applied to all the related enterprises in the country. The Ministry of Labor and Social Security (STPS) is given the authority to inspect the production, repair and operation of steam generators and high pressure vessels.

Capability of personnel for combustion equipment other than boilers is not subject to any legal regulation at present. The requirements of personnel engaged in the operation of boilers is prescribed in the said regulation as shown below:

| | |
|---|---|
| All categories: | to be 21 years old or more |
| Plant master: | (a) to have a bachelor's degree in a directly and sufficiently related field and to have experience of work under a senior plant master for more than one continuous year, or<br>(b) to have work experience as a naval or railroad mechanic, or as a plant master for more than two continuous years. |
| Operator: | (a) to have work experience as a fireman for more than three years, certified by documents, and to pass the due written examination, or<br>(b) to know the working of pressure vessels and be in possession of a fireman's, certificate and to pass the written examination. |
| Fireman: | to have experience as a fireman for more than six months and to pass the due written examination. |

These specified personnel are registered at the office of General Directorate of Social Security, the Ministry of Labor and Social Security. Those boilers of specific scales and locations are required to be operated by the qualified personnel as indicated in the regulation.

### 2.7.2 Voluntary Capacity Development of Operators

Besides satisfying the legal requirements, voluntary development of the ability 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. The outline of the course is as follows:

| | |
|---|---|
| Subject: | Energy saving in operation of boilers, direct heating furnaces and electric furnaces |
| Training method: | Lectures and practices with real facilities hired from plant owners |
| Duration of time: | 40 hours (one week for each type of combustion equipment) |
| Interval: | Once a year (usually in August and September) |
| Potential trainee: | Technicians engaged in operation or maintenance of the said facilities |
| Instructor: | Invited from outside (private consultants or experts of national institutes) |
| Fee: | N$ 1,500 for the course of 40 hours |

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

A voluntary association named ATPAE (Asociación de Técnicos y Profesionales en Aplicación Energéticas) also presents a one-week seminar annually on the subjects related to energy saving and environmental protection.

# CHAPTER 3 INVESTIGATION OF STATIONARY AIR POLLUTION SOURCES IN ZMCM

## Chapter 3 Investigation of Stationary Air Pollution Sources in ZMCM

Investigations were made to know the actual situations of combustion management, pollutant emissions and their control at combustion facilities in the stationary sources in ZMCM. A more comprehensive investigation was conducted previously by JICA in 1990 - 1991 in the Study on the Air Pollution Control Plan of Stationary Sources in the Metropolitan Area of the City of Mexico (hereinafter called "the previous JICA study"). In the present Study, investigations and analyses were made primarily on boiler facilities regarding the improvements made since the time of the previous JICA study and problems associated with them.

### 3.1 Kinds of the Investigation and Selection of Objective Sources

In the previous JICA study, a survey was made by visiting about 100 factories or other establishments. They were selected from the SEDUE's basic data for several hundred companies and the lists of service and commercial institutions whose control is the responsibility of DDF and GEM. The selection of objective sources was made applying one of the following conditions:

a) Following 25 factories or facilities as specified in the scope of work for the objects of diagnostic survey:

   Power plants (2)
   Petroleum refinery (1)
   Industrial boilers (10)
   Special industrial furnaces (9)
   Chemical plants (3)

b) Large scale factories

c) Sources of large amounts of pollutant emission

d) Representative boiler facilities in service and commercial institutions whose emission control is the responsibility of DDF and GEM.

The number of factories or institutions where the survey was actually able to be conducted was 97. Out of these 97, those selected under the condition a) shown above were further investigated through the diagnostic survey including flue gas measurements.

In the present Study, the following surveys were made in accordance with the Scope of Work for the Study.

(1) Synoptic Survey of Factories by Questionnaire

A questionnaire form was distributed to about 100 factories. They were selected as follows:

- Existing factories excluding the service and commercial institutions out of the 97 enterprises visited in the previous JICA study

- Factories newly selected by INE according to the conditions b) and c) above

However, effective answers were obtained from only 47 factories.

(2) Diagnostic Survey of Selected Factories

The diagnostic survey was conducted mainly on boilers in the 25 factories selected from the 47 factories which answered the questionnaire in the synoptic survey. The selection was made as follows:

1) 16 factories selected from the 25 establishments where the diagnostic survey was conducted in the previous JICA study, by excluding the service and commercial institutions, the closed factory, and including the only glass factory

2) 9 factories selected from INE according to the conditions b) and c) mentioned above

Flue gas measurements were also conducted at 13 factories selected from the factories of 1) above by excluding those where automatic measurements of flue gas are practiced.

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

Among the service and commercial institutions in ZMCM having boilers, 10 relatively large institutions were selected by DDF and GEM and visited by the Study Team. The diagnostic survey was made on the boilers at 5 of the institutions, by excluding one which refused to be surveyed and 4 where the diagnosis of the boilers including calculation of the boiler efficiency was not possible because there were no measuring devices for water and fuel consumption.

## 3.2 Synoptic Survey of Factories by Questionnaire

### 3.2.1 Method of the Survey

To initiate the survey, an explanatory meeting was convened by INE on August 12, 1993 at the auditorium of the Association of Paper and Pulp Industry. Over 30 enterprises dispatched about 50 attendants to the meeting. At the meeting, attendants were given an explanation of the purpose of this survey and guidance for replying to the questionnaire. The questionnaire items and the answer format are shown in Data Book. To those enterprises who did not send an attendant, the questionnaire form was delivered by INE. By the end of September 1993, 47 enterprises submitted answers concerning a total of 143 prices of combustion equipment.

### 3.2.2 Result of the Survey

Details of the result of the survey are shown in Data Book.

The situations of factories in view of NOx emission reduction and energy saving, in comparison to the earlier situations during the time of the previous JICA study, are as follows:

| | |
|---|---|
| a. No improvement was found: | 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 |

## 3.3 Diagnostic Survey of Selected Factories

### 3.3.1 Objectives and Method of the Survey

(1) Objectives of the Survey

Among the 47 factories which provided the information on their combustion facilities, those numbered from No. 1 to No. 25 (see Data Book) were subjected to the diagnostic survey. Flue gas measurement was made for combustion facilities in 13 factories (No. 1 through No. 10 and No. 12 through No. 14) out of those 25 factories. Objectives of the diagnostic survey were as follows :

1) Comparison with the results of the previous JICA study, regarding:

Evaluation of combustion equipment and progress in their renewal
Present situation of fuel change and consequent replacement of burners
Existence of energy saving equipment
Present situation of safety control equipment
Present situation of combustion control equipment
NOx reduction measures adopted

2) Comparison with the NOx emission standards reinforced after the previous JICA study and evaluation

3) Measurement of combustion efficiency and its evaluation

4) Present situation of low-oxygen combustion and its evaluation

(2) Classification of the Selected Factories

Classifications of the selected 25 factories by the kinds of fuel and combustion equipment are 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 |

(3) Items and Methods of the Diagnostic Survey

1) Evaluation of combustion equipment

2) Evaluation of fuel usage and combustion state

3) Measurements of flue gas and combustion efficiency at 13 selected factories

4) Discussion with responsible personnel for operation of combustion equipment

5) Flue gas measuring items and equipment

a. NOx
NOA-305A chemi-luminescence type made by Shimazu Co., Ltd.
Span gas: 292 ppm

b. $O_2$, CO, unburnt matter (HC), $CO_2$ and combustion efficiency
MAX5 made by Teledyne Analytical Instruments
$O_2$ span gas : 20.9%
CO span gas : 909 ppm
Span gas for combustibles (HC): 3.5%

c. Flue gas temperature
K thermocouple

6) Calculation of combustion efficiency

$$\text{Efficiency} = 100 - K3 - (K1 * T) / [K2 * (1 - O_2 / 21)]$$

where,
- T: exhaust gas temperature (°C)
- $O_2$: oxygen concentration in the exhaust gas (%)
- K1: correction factor for fuel composition
- K2: theoretical maximum $CO_2$ concentration
- K3: correction factor for latent heat (wet losses)

| | K1 | K2 | K3 |
|---|---|---|---|
| Natural gas | 0.38 | 11.8 | 11.0 |
| Gas oil | 0.56 | 15.6 | 6.0 |

### 3.3.2 Results of the Survey

Results of the diagnostic survey are summarized below. Details are given in Data Book.

(1) [No.1] Petrochemical Products Factory (A)

1) Name of facility surveyed: Process boiler (13 ton/hr) (Fuel : gas oil)

2) Combustion efficiency during the survey: 84%

3) NOx emission control measures being employed: Fuel change from heavy oil to gas oil in 1992.

4) Exhaust gas measuring equipment: None

5) NOx concentration in the exhaust gas

| | | |
|---|---|---|
| Measured by (date) | : | Study Team (Feb. 1, 1994) |
| Concentration (standard) | : | 98 ppm (150 ppm) |

6) Comments

(i) The concentration of NOx in the exhaust gas satisfies the emission standard.

(ii) The NOx concentration value of 321 ppm reported in the questionnaire survey is too high and is considered to be a mismeasurement. The factory stopped operation of other power generation boilers (No.1 and No.2) without inquiring into the mismeasurement.

(iii) Modification of the burner corresponding to the fuel change has not been made; its necessity has not been recognized. Installation of operation control equipment is not adequate, although the boiler is equipped with a fuel flow meter and a pressure gauge.

7) Recommended measures

(i) Burner reconstruction corresponding to the fuel change: e.g., selection of an atomizing nozzle suitable to the fuel change.

(ii) Installation of adequate operation control equipment for stable operation.

(iii) Installation of economizer or recuperator for energy saving.

(2) [No.2] Rubber Products Facotry (A)

1) Name of facility surveyed: Process boiler (12 ton/hr) (Fuel : gas oil)

2) Combustion efficiency during the survey: 74%

3) NOx emission control measures being employed

All the burner units were changed to low-NOx burners in 1992.

4) Exhaust gas measuring equipment: oxygen control unit

5) NOx concentration in the exhaust gas

| | | |
|---|---|---|
| Measured by (date) | : | Study Team (Feb. 2, 1994) |
| Concentration (standard) | : | 100 ppm (150 ppm) |

6) Comments

(i) Although the oxygen control unit is installed, combustion state of the burner is not good; the oxygen control unit is not effectively utilized.

(ii) Although the NOx concentration of the exhaust gas satisfies the emission standards, the amount of CO generation is large and black smoke from the stack is observable by eye.

(iii) Generally, over-reliance on control equipment and makers' catalogues is noticeable.

7) Recommended measures

(i) Reconstruction of the burners to enable low oxygen combustion.

(ii) Improvement of technical quality of engineers and operators in charge.

(iii) Collection of spent steam drains.

(3) [No.3] Petrochemical Products Factory (B)

1) Name of facilities surveyed : Process boiler (14 ton/hr)
Power generation boiler (28 ton/hr)
(Fuel : natural gas)

2) Combustion efficiency during the survey

Process boiler : 81%
Power generation boiler : 82%

3) NOx emission control measures being employed: Fuel change to natural gas

4) Exhaust gas measuring equipment: oxygen meter

5) NOx concentration in the exhaust gas

| | | | | |
|---|---|---|---|---|
| Measured by (date) | : | Study Team (Feb. 3, 1994) | | |
| Concentration (standard) | : | Process boiler | : | 60 ppm (130 ppm) |
| | | Power generation boiler | : | 75 ppm (120 ppm) |

6) Comments

(i) The process boiler is not equipped with energy saving equipment, but the power generation boiler is equipped with a recuperator for heat recovery.

(ii) The exhaust gas NOx concentrations of both boilers sufficiently satisfy the emission standards.

(iii) The plant seems to have a forward-looking stance in NOx emission reduction and energy saving.

7) Recommended measures

(i) Energy saving measures for the process boiler: economizer or recuperator

(ii) More effects are expected by employment of the biased method and the steam injection method as a next step of NOx control.

(4) [No.4] Paper Factory (A)

1) Name of facility surveyed: Process boiler (16 ton/hr)
(Fuel : natural gas)

2) Combustion efficiency during the survey: 74%

3) NOx emission control measures being employed: Change of fuel from heavy oil to natural gas in 1992

4) Exhaust gas measuring equipment: thermometer for exhaust gas

5) NOx concentration in the exhaust gas

| | | |
|---|---|---|
| Measured by (date) | : | Study Team (Feb. 4, 1994) |
| Concentration (standard) | : | 55 ppm (130 ppm) |

6) Comments

(i) The boiler was renewed at the time of the fuel change. Although sequential control of the burner is adopted, boiler operation control equipment is not adequate.

(ii) An economizer is installed for energy saving.

(iii) The oxygen concentration of the exhaust gas is as high as 8%.

(iv) Although the necessity of boiler operation control equipment is fully recognized, it is not practiced.

7) Recommended measures

(i) Installation of adequate control equipment for the boiler and the economizer.

(ii) Efforts for low oxygen combustion (this burner can be operated at about 2% oxygen).

(5) [No.5] Thermoelectric Power Plant (A)

1) Name of facilities surveyed : Power generation boiler No.1, No.2 (150 ton/hr each)
Power generation boiler No.3, No.4 (350 ton/hr each)
(Fuel : natural gas)

2) Combustion efficiency during the survey:

| | | |
|---|---|---|
| No.1 boiler | : | 69% |
| No.4 boiler | : | 79% |

3) NOx emission control measures being employed

The mixed combustion of heavy oil and natural gas was changed to natural gas only in September 1991.

4) Exhaust gas measuring equipment: thermometers for exhaust gas

5) NOx concentration in the exhaust gas

| | | | | |
|---|---|---|---|---|
| Measured by (date) | : | Study Team (Feb. 7, 1994) | | |
| Concentration (standard) | : | No.1 boiler | : | 337 ppm (100 ppm) |
| | | No.4 boiler | : | 70 ppm (100 ppm) |

6) Comments

(i) Boiler No.1

i) According to the data as of September 1993, presented by the plant at the time of the survey, the exhaust gas NOx concentration was 343 ppm at 90% of the rated capacity. The measurement by the Study Team showed a similar level at 337 ppm at 60% of the rated capacity.

ii) The cause of the high NOx concentration is considered to be the structure of the combustion chamber in which there are local regions where the temperature is very high (red-hot furnace wall observed) and detention time of the combustion gas is long.

iii) No.2 boiler that was not in operation at the time of the survey is of the same structure. Its NOx concentration shown in the questionnaire was as high as that of No.1 boiler.

iv) The cause of CO generation is considered to be the inappropriate positioning of the 6 burners.

(ii) Boiler No.4

The operation is in good conditions with low NOx concentration, low oxygen level and no CO generation.

7) Recommended measures

(i) Both No.1 and No.2 boilers are about 40 years of age with low power generation efficiency and high concentration of NOx in the exhaust gas. Since it seems that the time has come for renewal of the facilities, employment of an advanced combined cycle (latest combined gas turbine with waste heat utilization) equipped with exhaust gas denitration is desirable.

(ii) Although the NOx concentrations of No.3 and No.4 boilers are of low level, the NOx emission amount is large. Therefore, further NOx reduction measures such as installation of exhaust gas recirculation (EGR) system are recommended.

(6) [No.6] Paper Products Factory (A)

1) Name of facility surveyed: Process boiler No.1 (9.5 ton/hr) (Fuel : gas oil)

2) Combustion efficiency during the survey: 81%

3) NOx emission control measures being employed

(i) Fuel was changed from heavy oil to gas oil in 1991.

(ii) An additive for sediments dispersion is mixed into gas oil.

4) Exhaust gas measuring equipment

There is no fixed type measuring equipment. A portable type device (ENERAC, Model 2000) is used for measuring combustion efficiency, exhaust gas temperature, oxygen, CO, $CO_2$, NOx, and $SO_2$.

5) NOx concentration in the exhaust gas

| | | |
|---|---|---|
| Measured by (date) | : | Study Team (Feb. 8, 1994) |
| Concentration (standard) | : | 110 ppm (150 ppm) |

6) Comments

(i) Combustion state is satisfactory. The oxygen concentration limit for smoke generation is 1.5%.

(ii) The NOx concentration of the exhaust gas measured this time was below the emission standard value. The plant is still highly concerned with the NOx reduction, and requested Japanese technical cooperation to reduce the NOx concentration to the 70 ppm level.

(iii) Introduction of an economizer is being planned. Materials of the heat exchanger should be carefully selected considering the use of gas oil.

7) Recommended measures

(i) Installation of an economizer

(ii) Introduction of NOx reduction measures such as EGR, steam injection and others

(iii) Boiler operation control by installing necessary flow meters.

(7) [No.7] Paper Products Factory (B)

1) Name of facility surveyed: Process boiler No.2, No.3 and No.5 (7.8 ton/hr each) (Fuel : gas oil)

2) Combustion efficiency during the survey:
No.2: 86%
No.3: 87%
No.5: 83%

3) NOx emission control measures being employed

Fuel was changed from heavy oil to gas oil in November 1992.

4) Exhaust gas measuring equipment: thermometer for exhaust gas only

5) NOx concentration in the exhaust gas

| | | | | |
|---|---|---|---|---|
| Measured by (date) | : | Study Team (Feb. 9, 1994) | | |
| Concentration (standard) | : | No.2 | : | 134 ppm (150 ppm) |
| | | No.3 | : | 113 ppm (150 ppm) |
| | | No.5 | : | 147 ppm (150 ppm) |

6) Comments

(i) No burner modification was made at the time of the fuel change.

(ii) Poor provision of boiler operation control equipment (esp. no flow meter)

(iii) Although the exhaust gas NOx concentrations of 130 - 140 ppm are below the emission standard value, the concentration is likely to exceed that at higher combustion loads.

7) Recommended measures

(i) Adequate boiler operation control equipment should be provided. Especially, a fuel supply flow meter should be provided.

(ii) Energy saving measures such as economizer or drain recovery.

(iii) Change from air atomizing to steam atomizing.

(8) [No.8] Chemical Products Factory (A)

1) Name of facility surveyed: Process boiler (3.1 ton/hr)
(Fuel : gas oil)

2) Combustion efficiency during the survey: 82%

3) NOx emission control measures being employed

Fuel change was made in 1992: from heavy oil to gas oil for the boiler, and from diesel only to gas oil (50%) + diesel (50%) for the triacetate furnace.

4) Exhaust gas measuring equipment: none

5) NOx concentration in the exhaust gas

Measured by (date) : Study Team (Feb. 9, 1994)
Concentration (standard) : 200 ppm (150 ppm)

6) Comments

(i) The NOx concentration of the exhaust gas exceeded the emission standard value. It is because that the volumetric and the sectional combustion chamber loads are high, and also the oxygen concentration of the exhaust gas is high.

(ii) Energy saving efforts are being made by recovering 50 - 60% of the spent drain.

(iii) The triacetate furnace is of small capacity (less than 10 lit/hr). No particular measure is necessary.

(iv) The plant is planning further fuel change: from gas oil to natural gas.

7) Recommended measures

(i) Employment of steam atomization and a low-NOx burner as NOx reduction measures.

(ii) Boiler operation control by installing necessary flow meters.

(9) [No.9] Chemical Products Factory (B)

1) Name of facility surveyed: Process boiler No.3 (9.4 ton/hr) (Fuel : natural gas)

2) Combustion efficiency during the survey: 82%

3) NOx emission control measures being employed

No particular NOx reduction measures are considered because of the use of natural gas from the beginning.

4) Exhaust gas measuring equipment

A handy type measuring device is used to measure NOx, oxygen, CO, $CO_2$, $SO_2$.

5) NOx concentration in the exhaust gas

Measured by (date) : Study Team (Feb. 11, 1994)
Concentration (standard) : 87 ppm (130 ppm)

6) Comments

(i) Keen on collection of technical information on NOx reduction measures for the future.

(ii) Drain recovery is partially employed, but the amount of the recovery is unknown.

(iii) A gas flow meter installed is for measuring the plant's total consumption according to the contract with the gas company. It should be also provided for each boiler before the burner.

(iv) Water supply meter is also not provided.

7) Recommended measures

(i) Enhancement of drain recovery.

(ii) Adequate provision of boiler operation control equipment, especially flow meters.

(10) [No.10] Alcoholic Drinks Factory

1) Name of facilities surveyed : Power generation boiler No. 3225 (27 ton/hr)
Power generation boiler No. 4884 (60 ton/hr)
Power generation boiler No. VU-60II (82 ton/hr)
(Fuel : natural gas)

2) Combustion efficiency during the survey: No. 3225 : 80%
No. 4884 : 78%
No. VU-60II : 77%

3) NOx emission control measures being employed

(i) EGR has been installed on No.4884 boiler (60 ton/hr), and is now being installed on a 100 ton/hr boiler.

(ii) Preparation for installation of EGR is underway for No.VU-60II boiler, and the installation will be made following the completion of the work for the 100 ton /hr boiler.

4) Exhaust gas monitoring equipment

A continuous exhaust gas monitoring system is now being tested. The system can be used for exhaust gas from any of the existing boilers to measure NOx, CO, $CO_2$, $SO_2$ and oxygen concentrations. Maker is ALTECH SYSTEM.

5) NOx concentration in the exhaust gas

| | | | | |
|---|---|---|---|---|
| Measured by (date) | : | Study Team (Feb. 14, 1994) | | |
| Concentration (standard) | : | No.3225 | : | 110 ppm (120 ppm) |
| | | No.4884 | : | 34 ppm with EGR (120 ppm) |
| | | No. VU-60II | : | 97 ppm (120 ppm) |

6) Comments

(i) Since the recirculation rate of the EGR system for No. 4884 boiler is too high, CO generation is as high as 320 ppm.

(ii) Insufficient attention is paid to the generation of CO.

(iii) Boiler operation control equipment is generally adequate.

(iv) In April through October, the boilers use gas oil only or a mix of natural gas and gas oil. However, in occasions of the government warning for a high degree of air pollution, only the natural gas is to be used.

7) Recommended measures

(i) Early completion of EGR installation works for all the boilers

(ii) Promotion of applying appropriate exhaust gas recirculation rates; target CO concentration of exhaust gas should be 0.

(11) [No.11] Cement Factory

1) Name of facility surveyed: Cement kiln No.7 and No.9
(Fuel : heavy oil)

2) Combustion efficiency: not measured

3) NOx emission control measures being employed

No measure is taken for No.7 kiln. Burners in No.9 kiln were changed to low-NOx burners (PILLARD ROTAFLAM).

4) Exhaust gas measuring equipment

Exhaust gas compositions of 3 kilns, i.e., No.7, No.8 (under regular maintenance works), and No.9, are continuously monitored through the data logger introduced in November 1991.

5) NOx concentration in the exhaust gas

| | | | | |
|---|---|---|---|---|
| Measured by (date) | : | the plant (Feb. 15, 1994) | | |
| Concentration (standard) | : | No.7 | : | 343 ppm |
| | | No.9 | : | 320 ppm |

No emission standard for NOx is provided for cement kilns.

6) Comments

(i) This plant is the only one which uses heavy oil (bunker C) in ZMCM.

(ii) Exhaust gas analysis data from the data logger are regularly submitted to INE.

7) Recommended measures

(i) Installation of precalciners to the SP kilns and installation of ducts for sending hot air from the clinker cooler to the precalciners in order to achieve energy saving.

(ii) Efforts for low air ratio combustion

(12) [No.12] Paper Products Factory (C)

1) Name of facility surveyed: Process boiler No.1 (8 ton/hr) (Fuel : gas oil)

2) Combustion efficiency during the survey: 85%

3) NOx emission control measures being employed

Fuel was changed from heavy oil to gas oil in December 1991.

4) Exhaust gas measuring equipment:

There are no fixed monitoring devices. The portable combustion test equipment (ENERAC 200) co-owned with the adjacent small carton manufacturing branch is used for the measurement.

5) NOx concentration in the exhaust gas

| | | |
|---|---|---|
| Measured by (date) | : | Study Team (Feb. 16, 1994) |
| Concentration (standard) | : | 65 ppm (150 ppm) |

6) Comments

(i) This boiler and the boiler in the adjacent small carton branch are operated by the same operators, who are well aware of the importance of NOx reduction and energy saving.

(ii) A coil type economizer made from carbon steel is installed within the stack.

(iii) The exhaust gas analysis data show no particular problems of oxygen and NOx concentrations.

(iv) The exhaust gas temperature of this boiler equipped with the economizer is 180 °C which is lower than that of the boiler (9.5 ton/hr) in the adjacent small carton branch. The temperature should be kept above 160 °C for prevention of corrosion.

7) Recommended measures

Further reduction of NOx emission can be achieved by the following measures.

(i) Low-NOx burner

(ii) Employment of measures such as EGR and steam injection

(iii) Enhancement of boiler operation control by appropriate measures such as installation of a water supply flow meter and measurement of boiler efficiency.

(13) [No.13] Paper Factory (B)

1) Name of facility surveyed: Process boiler (45.4 ton/hr)
(Fuel : natural gas)

2) Combustion efficiency during the survey: 72%

3) NOx emission control measures being employed

The plant stated that no measures were necessary for control of NOx and CO, because both met the regulated values. However, the result of the measurement showed otherwise.

4) Exhaust gas measuring equipment

A continuous exhaust gas monitoring system (ALTEC system) was installed in July 1993 for monitoring NOx, CO, $SO_2$, and oxygen concentrations, and the system is now being tested. However, the standard gas cylinders for NOx measurement had been empty for one week.

5) NOx concentration in the exhaust gas

| | | |
|---|---|---|
| Measured by (date) | : | Study Team (Feb. 17, 1994) |
| Concentration (standard) | : | 140 ppm (120 ppm) |

6) Comments

(i) The plant stated that the responsibility for the abnormally low value of the exhaust gas NOx concentration reported in the questionnaire belonged to the measurement service company.

(ii) The plant is keen on energy saving and air pollution control; they practice drain recovery and installed a continuous exhaust gas monitoring system. However, since NOx and CO concentrations exceed the regulated values, change of burner is desirable.

7) Recommended measures: Change of the burner to the ring type

(14) [No.14] Chemical Products Factory (C)

1) Name of facilities surveyed : Process boiler B (15.5 ton/hr)
Process boiler D (6 ton/hr)
(Fuel : natural gas)

2) Combustion efficiency during the survey: Boiler B : 78%
Boiler D : 79%

3) NOx emission control measures being employed

Since natural gas is used as fuel, no particular measure is considered by the plant.

4) Exhaust gas measuring equipment: Orsat analyzer

5) NOx concentration in the exhaust gas

| | | | | |
|---|---|---|---|---|
| Measured by (date) | : | Study Team (Feb. 18, 1994) | | |
| Concentration (standard) | : | No.B | : | 77 ppm (130 ppm) |
| | | No.D | : | 88 ppm (130 ppm) |

6) Comments

(i) There were mistakes in the answer to the questionnaire concerning methods of exhaust gas analysis.

(ii) The concentrations of NOx and CO in the exhaust gas measured this time satisfied the emission standard values.

(iii) There are an adequate number of chemical engineers in the plant, but there is only one boiler operator, that is not sufficient for a plant having 6 boilers.

(iv) Since energy saving measures are not sufficient, the factory plans to install a recuperator.

7) Recommended measures

(i) Introduction of a recuperator may cause higher exhaust gas NOx concentration due to increased combustion air temperature. In such a case, NOx reduction measures such as steam injection are necessary.

(ii) Boiler operation control equipment, particularly flow meters, should be adequately provided.

(15) [No.15] Metal Products Factory (A)

1) Name of facility surveyed: Aluminum melting furnace (20 ton/charge)
(Fuel : natural gas)

2) NOx emission control measures being employed: None because of use of natural gas

3) Exhaust gas measuring equipment: None

4) NOx concentration in the exhaust gas

| | | |
|---|---|---|
| Measured by (date) | : | measurement company (regular) |
| Concentration (standard) | : | 10 ppm (not applicable) |

5) Comments

(i) Exhaust gas measurement is made regularly by a measurement service company under contract to the plant.

(ii) Exhaust gas management is made through a stack installed on this small capacity furnace.

6) Recommended measures

(i) No NOx control measure is necessary since the NOx concentration is low.

(ii) Management of combustion efficiency by installing a fuel flow meter.

(16) [No.16] Textile Factory

1) Name of facility surveyed: Process boiler (8.3 ton/hr)
(Fuel : gas oil)

2) NOx emission control measures being employed

Heavy oil fuel was changed to gas oil after the notice was given by PEMEX in the autumn of 1991 that the supply of heavy oil was no longer possible.

3) Exhaust gas measuring equipment

Smoke tester, gas detection tube, MAX 5, and smoke and soot measuring device, all of the portable type

4) NOx concentration in the exhaust gas

| | | |
|---|---|---|
| Measured by (date) | : | measurement company (not clear) |
| Concentration (standard) | : | 3.8 ppm (150 ppm) |

5) Comments

(i) A person who had been in charge of the boiler operation quit, and no successor was appointed yet. The answers of the plant to the questions of the Study Team were not reliable because of insufficient technical grounds.

(ii) Safety control of the boiler is not reliable.

(iii) The NOx concentration of exhaust gas given in the answer to the questionnaire was the unreasonably low value of 3.8 ppm. When the Study Team asked about the validity of the measurement data to the consultant who was entrusted by the plant, no concrete answer was given.

(iv) Change of gas oil to natural gas is being planned.

6) Recommended measures

(i) Technical training of personnel for boiler operation and maintenance

(ii) Improvement of boiler efficiency aided by installation of necessary control equipment

(17) [No.17] Paper Products Factory (D)

1) Name of facility surveyed: Power generation boiler (107 ton/hr)
(Fuel : natural gas)

2) NOx emission control measures being employed

The plant uses natural gas only and the boiler exhaust gas meets the emission standards. Therefore, no NOx reduction measures are employed at present. However, the plant is consulting with boiler makers on possible measures in view of prospects for tighter regulations in the future.

3) Exhaust gas measuring equipment

The plant has a Bacharach #300 unit which is capable of measuring oxygen, $CO_2$, $SO_2$, and NOx.

4) NOx concentration in the exhaust gas

| | | |
|---|---|---|
| Measured by (date) | : | the plant (Nov. 1993) |
| Concentration (standard) | : | 90 ppm (100 ppm) |

5) Comments

(i) The oxygen concentration at 6% is high for combustion of natural gas only. Operation at 3% oxygen is desirable.

(ii) The plant is keen on energy saving; they are employing an economizer and recovering drain.

(iii) Boiler operation control equipment is generally adequate.

6) Recommended measures

Modification of the burner for enabling low-oxygen operation

(18) [No.18] Glass Factory (A)

1) Name of facility surveyed: Melting furnace for glass fiber material
(30.5 ton/day)
(Fuel : natural gas)

2) NOx emission control measures being employed: Use of oxygen burners

3) Exhaust gas measuring equipment: Oxygen analyzer

4) NOx concentration in the exhaust gas

| | | |
|---|---|---|
| Measured by (date) | : | measurement company (Jan. 1994) |
| Concentration (standard) | : | 6 ppm (not applicable) |

5) Comments

(i) The plant is investing in energy saving and air pollution control (exhaust gas and dust control) based on a comprehensive 3 year plan from 1993.

(ii) Damage to refractory bricks of the furnace is noticeable, and presumed to have been caused by the furnace temperature of 1,550 °C whereas the bricks used are suitable for up to 1,500 °C.

(iii) Employment of oxygen burners has resulted in NOx emission reduction and energy saving. The present exhaust gas NOx concentration is reported to be 6 ppm as compared with 1,200 ppm at the time of the previous JICA study. The plant explained that due to high temperature combustion by oxygen burners, total energy was being saved to the extent of 5%. However, certain measures are necessary for the problem stated in ii) above.

6) Recommended measures

(i) Repair of the furnace body and use of refractory bricks resistant to higher temperature

(ii) Improvement in precision of the furnace body, by use of an appropriate construction method

(19) [No.19] Chemical Products Factory (D)

1) Name of facilities surveyed : Heating furnace (200 ton/charge)
Process boilers (9.4 ton/hr x 2)
Process boiler (6.2 ton/hr)
(Fuel : natural gas)

2) NOx emission control measures being employed: Use of natural gas only

3) Exhaust gas measuring equipment

ENERAC 2000 (portable type) is used for measurements of oxygen, CO, $CO_2$, NOx, and $SO_2$ concentrations in the exhaust gas and combustion efficiency.

4) NOx concentration in the exhaust gas

| | | |
|---|---|---|
| Measured by (date) | : | the plant (Dec. 1992) |
| Concentration (standard) | : | heating furnace : 500 ppm at 17% $O_2$ (not applicable) |
| | | boilers : no data (130 ppm) |

5) Comments

(i) Heating furnace

i) The ceiling height of the furnace was changed, in December 1992, from 5 m to 3.5 m. As a result, unit fuel consumption decreased from 150 $m^3$/ton to 115 $m^3$/ton and operation efficiency improved.

ii) The smoke dust concentration data in January 1994 satisfied the emission standard.

iii) Meetings are regularly held by the group companies on energy saving. A major topic has been the improvement of facilities such as for exhaust gas utilization, and effective measures have been realized.

iv) A gas flow meter is installed for each of 4 gas burners.

(ii) Boilers

No measure has been taken after the fuel change to natural gas only.

6) Recommended measures

(i) Heating furnace

i) The NOx concentration increases as the combustion efficiency increases. Reduction of NOx generation should be tried out of consideration of cost efficiency.

ii) Use of quality insulating material to reduce heat loss through the furnace wall.

(ii) Boilers

Installation of economizers to raise the temperature of the supply water as a energy saving measure.

(20) [No.20] Chemical Products Factory (E)

1) Name of facility surveyed: Process boiler (6.0 ton/hr)
(Fuel : natural gas)

2) NOx emission control measures being employed

This boiler for natural gas combustion was newly installed. Operation of the old one using diesel oil has been suspended, but it has not been abandoned so that it can be used in an emergency.

3) Exhaust gas measuring equipment

A continuous exhaust gas monitoring system for measurements of NOx, CO, $CO_2$, $SO_2$ and oxygen concentrations and a thermometer are installed.

4) NOx concentration in the exhaust gas

| | | |
|---|---|---|
| Measured by (date) | : | the plant (Feb. 8, 1994) |
| Concentration (standard) | : | 43 ppm (130 ppm) |

5) Comments

(i) Boiler operation control is being made including measurement of boiler efficiency.

(ii) Energy saving and increased combustion efficiency are being achieved by the renewal of boiler. The boiler efficiency of the boiler is 91%.

(iii) The plant seems to be keen on heat management and air pollution control.

6) Recommended measures: None in particular

(21) [No.21] Rubber Products Factory (B)

1) Name of facilities surveyed : Process boilers (3.1 ton/hr and 2.0 ton/hr)
Heat transfer medium process boiler (1,150 x 103 kcal/hr)
(Fuel : diesel oil)

2) NOx emission control measures being employed

Fuel was changed to diesel oil in 1992. Since then, the exhaust gas NOx concentration has been meeting the emission standard.

3) Exhaust gas measuring equipment

(i) A handy type equipment (made by Test Term) capable of measuring NOx, CO, $CO_2$, and oxygen concentrations and combustion efficiency

(ii) Orsat analyzer

4) NOx concentration in the exhaust gas

| | | | | |
|---|---|---|---|---|
| Measured by (date) | : | the plant (Feb. 8, 1994) | | |
| Concentration (standard) | : | 3.1 ton/h boiler | : | 104 ppm (150 ppm) |
| | | 2.0 ton/h boiler | : | 139 ppm (not applicable) |
| | | HTM boiler | : | 73 ppm (not applicable) |

5) Comments

(i) Under the overall plant reviewing program including production processes, energy saving efforts are being made with the target of 20% reduction of electricity, water and fuel consumption.

(ii) In consideration for energy saving on boilers, drain recovery was improved and heat insulation for steam piping was applied.

(iii) The plant is well aware of the necessity of boiler operation control using measuring equipment such as flow meters, and it is intended to install such equipment in the subsequent program.

(iv) From the above, the plant managers seem to have good understanding on energy saving and necessity of the measurements for operation control.

6) Recommended Measures

(i) Enhancement of drain recovery

(ii) Adequate installation of boiler operation control equipment, especially flow meters

(22) [No.22] Paper Factory (C)

1) Name of facility surveyed: Process boiler (60 ton/hr)
(Fuel : heavy oil)

2) NOx emission control measures being employed

The plant is located out of the metropolitan area, and uses heavy oil with the permission of the authorities.

3) Exhaust gas measuring equipment

The plant is planning installation of a continuous exhaust gas monitoring system capable of measuring NOx, $SO_2$, CO, $CO_2$ and oxygen.

4) NOx concentration in the exhaust gas

| | | |
|---|---|---|
| Measured by (date) | : | the plant (Feb. 1994) |
| Concentration (standard) | : | 150 ppm (230 ppm) |

5) Comments

(i) Energy saving measures employed are: a) installation of a recuperator, b) heat insulation of steam and other pipes, and c) calibration of burners, esp. in terms of the exhaust gas oxygen concentration.

(ii) There is no low water level shut-off device among the necessary combustion control equipment. Among necessary safety control equipment, a flame eye is not provided. These indicate that the safety of boiler operation is not adequately insured.

(iii) Although the concentration of smoke dust is within the limit of the emission standard (300 mg/Nm$^3$), it is relatively high at 277 mg/Nm$^3$. In case a more stringent emission standard is enforced in the future, smoke dust emission of the plant may not satisfy the standard.

6) Recommended measures

(i) Adequate provision of boiler combustion control equipment

(ii) Smoke dust emission control measures such as installation of a dust collector.

(23) [No.23] Rubber Factory

1) Name of facility surveyed: Process boiler (0.94 ton/hr) (Fuel : diesel oil)

2) NOx emission control measures being employed: none

3) Exhaust gas measuring equipment: Only an exhaust gas thermometer (bimetal type) is installed.

4) Comments

(i) This boiler is not subject to the emission regulation because of its small size. There is no record of the measurement of NOx emission.

(ii) Maintenance of the boiler is entrusted to a service company which is specialized in the maintenance of the burner. It is doubtful that the service company is capable of performing both works.

5) Recommended measures

(i) Management of fuel consumption per unit output by installing water supply and oil flow meters.

(ii) Exhaust gas oxygen control using a portable oxygen analyzer

(24) [No.24] Rubber Products Factory (C)

1) Name of facility surveyed: Process boiler (3.13 ton/hr) (Fuel : diesel oil)

2) NOx emission control measures being employed: Fuel was changed from heavy oil to diesel in 1992.

3) Exhaust gas measuring equipment: A portable type measuring device is used.

4) NOx concentration in the exhaust gas

| | | |
|---|---|---|
| Measured by (date) | : | the plant (not clear) |
| Concentration (standard) | : | 40 ppm (150 ppm) |

5) Comments

(i) Drain recovery is 100%. Steam pipe insulation is regularly inspected and leaks are repaired.

(ii) The plant stated a desire of changing from diesel oil to LPG. But it seems to not be necessary since the emissions of both NOx and smoke dust meet the respective emission standard.

6) Recommended measures

Management of boiler and fuel consumption per unit output by installing water supply and oil flow meters

(25) [No.25] Thermoelectric Power Plant (B)

1) Name of facilities surveyed : Power generation boiler U-1 (476 ton/hr)
Power generation boiler U-2 (504 ton/hr)
Power generation boiler U-3 (504 ton/hr)
Power generation boiler U-4 (905 ton/hr)
(Fuel : natural gas)

2) NOx emission control measures being employed

Natural gas only is used for all 4 boilers. EGR is employed for U-1 boiler.

3) Exhaust gas measuring equipment

All 4 boilers are equipped with a continuous exhaust gas monitoring system to measure NOx, oxygen, and CO concentrations, and a thermometer.

4) NOx concentration in the exhaust gas

| | | | | |
|---|---|---|---|---|
| Measured by (date) | : | the plant (not clear) | | |
| Concentration (standard) | : | U-1 | : | 55 ppm (100 ppm) |
| | | U-2 | : | 35 ppm (100 ppm) |
| | | U-3 | : | 40 ppm (100 ppm) |
| | | U-4 | : | 120 ppm (100 ppm) |

5) Comments

(i) The exhaust gas oxygen concentration is generally high as power generation boilers: 4.0% for U-1, U-2, U-3 boilers, and 6% for U-4 boiler.

(ii) The exhaust gas NOx concentration of U-4 boiler at 120 ppm exceeds the emission standard.

(iii) It is ideal to control the operation in terms of fuel consumption per unit output of electricity.

6) Recommended measures

(i) Reduction of NOx emission from U-4 boiler, e.g., by EGR.

(ii) Systematic control of boiler efficiency and unit power generation cost.

## 3.4 Diagnostic Survey of Boilers in Service and Commercial Institutions

### 3.4.1 Institutions Surveyed

A diagnostic survey of boilers in service and commercial institutions was conducted. Ten institutions were proposed by DDF and GEM and visited by the Study Team. The following five institutions were selected for the diagnosis on the basis that water and fuel consumption rates were measurable by some means.

| No. | Institution | Date of Visit (1993) | Number of Employees (Laborers) |
|---|---|---|---|
| 48 | Hospital (A) | July 28 | 610 (558) |
| 49 | Hospital (B) | July 29 | 132 |
| 50 | Hotel | July 30 | 850 |
| 51 | Medicine firm | August 3 | 170 (107) |
| 52 | Sport club | August 7 | 214 |

### 3.4.2 Result of the Survey

Results of the survey are summarized below. Details are given in Data Book.

(1) [NO.48] Hospital (A)

1) Facilities surveyed: Water-tube boilers No.1, No.2 and No.3 (1.96 ton/hr each) (Fuel : gas oil)

2) Observation

Three water-tube boilers of Queen City Engineering are used for utilities of the hospital. Of these, two were being operated at the time of the visit. One was operated at a fixed combustion rate of 50% loading (0.98 ton/h), and another was operated at a varying rate to meet variable demand of the steam.

Previously-used heavy oil was replaced by gas oil in 1990, but the burners for heavy oil are still used without any modification. Operations are made at high air ratios. The flames are luminous and carbon particle burning is partly observable around the flame heads indicating coarse particles of atomized gas oil.

3) Recommended measures

i) Change the air nozzles and the oil spraying heads of the burners to those for gas oil in order to have fine fuel particles. Operate at a low air ratio by adjusting the primary and secondary air dampers.

ii) Employ low-NOx burners and steam injection.

iii) Renew the boilers as commented on by the hospital.

(2) [No.49] Hospital (B)

1) Facilities surveyed :

Flue and smoke-tube boiler No.1 (9.4 ton/h)
Flue and smoke-tube boiler No.2 (2.5 ton/h)
Flue and smoke-tube boiler No.3 (1.5 ton/h)
Flue and smoke-tube boiler No.4 (5.5 ton/h)
(Fuel : diesel oil)

2) Observation

Three flue and smoke-tube boilers of Cleaver Brooks and one flue and smoke-tube boiler of Power Master are installed for utilities of the hospital. Boiler No.1 was operated at the time of the visit. The burner is of air-atomizing and semi-inner mixing type. The nozzle for heavy oil is used without modification.

The amount of combustion air is controlled by a variable slit linked to the drafting duct. The air reaches to the nozzle through a swirler. A perforated plate is provided circumferentially in the neighborhood of the nozzle jetting range. Refractory bricks form a front part of the inner wall of the combustion chamber. Therefore, when the fuel is sprayed at a wide angle, the refractory material may become red-hot thereby causing a high NOx concentration.

At the time heavy oil was replaced by diesel oil, the hospital made a test of changing atomizing medium from air to self-generated steam. It was said that the steam atomization caused the highly pulsating combustion, therefore, the hospital employed the air atomization. This phenomenon is considered to be caused by a large amount of drain mixed in the steam. It is recommended to try the steam atomization combustion again.

A comparative study on the existing nozzle having a perforated plate and a low-NOx steam atomizing nozzle is desirable.

All 4 boilers have a simple dust collector on the top of the stack. They were installed when heavy oil was used aiming to prevent emission of acid mud which was falling on the nearby roads and automobiles. They are said to have a considerable effect.

3) Recommended measures

i) Change the burner nozzles to the type suitable for diesel oil and operate at an appropriate air ratio.
ii) Use low-NOx burners
iii) Employ exhaust gas recirculation and steam injection combustion.
iv) Install an oil supply flow meter and a water supply flow meter on each boiler for regular checking of boiler efficiency and energy saving.

(3) [No.50] Hotel

1) Facility surveyed: Flue and smoke-tube boiler No.2 (7.84 ton/h)
(Fuel : LPG)

2) Observation

Three flue and smoke-tube boilers of Cleaver Brooks are installed for utilities of the hotel. No.1 and No.2 boilers are for LPG combustion, and No.3 boiler is a spare specified for diesel combustion. At the time of the visit, only No.2 boiler was operated under automatic control.

The central part of the flame was transparent. Combustion begins in the vicinity of the end of the burner tile with a violet-red flame. The combustion chamber heat load exceeded 1,000,000 $kcal/m^3h$. The chamber inner wall is formed by refractory bricks up to about 1.5 m from the burner. The bricks may be red-heated at high load combustion resulting in a high concentration of NOx.

3) Recommended measures

i) Employ low-NOx burners and steam injection combustion.
ii) Install a inflammable gas detection and warning system in the boiler room located in the second basement floor.
iii) Install a fuel supply flow meter and a water supply flow meter on each boiler for regular checking of boiler efficiency and energy saving.

(4) [No.51] Medicine Firm

1) Facility surveyed: Boiler (1.17 ton/hr)
(Fuel : diesel oil)

2) Observation

The boiler is of the horizontal and multi-tube type, and the steam is used for drying chemicals. The particle size of the atomized diesel fuel was coarse. Since the combustion chamber load was low at 230,000 $kcal/hm^3$, one may consider the NOx concentration to be low also. However, since the actual boiler efficiency was 60% in comparison to the design efficiency of 70%, and non-uniformity of heat distribution is possible due to the boiler structure, the NOx concentration may become high.

3) Recommended measures

i) Improvement of the boiler efficiency
ii) Change the natural draft to the forced draft, and precisely control the oxygen concentration.
iii) Renew the boiler

(5) [No.52] Sport Club

1) Facilities surveyed: Water-tube boiler No.2 (9.0 ton/h)
Boiler (5.0 ton/h)
(Fuel : gas oil)

2) Observation

The steam boilers of Babcok & Wilcox de Mexico are used for warming swimming pool water and utilities in this sport and recreational center. Boiler No.2, (580 HP) was in operation at the time of the visit. The burner is of steam atomizing, outer mixing type which is widely used in Mexico City. This type tends to cause higher NOx concentration in comparison to inner mixing types.

The boiler was operated at combustion loading below 50% that gave a divergent flame shape. When the boiler load was increased, the flame converged. Operation at more than 50% loading is desirable. The flame was deflected because of the deflected flow of the combustion air. Upon the request of the Study Team, combustion was tried at nearly 100% of the rated capacity. There was still a considerable space left for the flame at the rear part of the combustion chamber.

There is an Orsat analyzer, but the regular monitoring of the exhaust gas is entrusted to a measurement company. The data for the past measurement on the exhaust gas show excess air combustion.

The burner unit is a modified version of COEN, USA. This type is also commonly used in Japan for medium-size boilers. There was a cavitation zone around the burner cap, and the back flow towards the burner shield was considerably high. Although the boiler loading was low, the NOx concentration was considered to be around the limit of the emission standard or slightly higher, since the nozzle is of the outer mixing type and the combustion was under conditions of excessive air with the exhaust gas oxygen concentration at 6 - 9%.

3) Recommended measures

i) Practice low-oxygen combustion as pointed out at the time of the visit in the previous JICA study.

ii) Consider change of the burner atomizer to the type enabling low NOx generation (change to an inner mixing type)

iii) Consider means to cause uniform flow of the combustion air at the burner throat.

iv) Install a fuel supply flow meter on each boiler, and consider improvement of boiler efficiency and energy saving.

## 3.5 Problem Summary and Discussion

### 3.5.1 Situation of Combustion Equipment

(1) Installation of Combustion Control Devices

Combustion equipment generally requires a set of combustion control devices. These devices have such functions as detecting and indicating operational conditions of the equipment, adjusting operational parameters and changing the operation mode. The minimum arrangement of combustion control devices of a boiler for safety and low-NOx operation is shown in Table 3.5.1 by type of fuel used. In the case when low-NOx combustion technologies are introduced, an automatic combustion control unit helps to achieve the purpose more efficiently and stably.

Table 3.5.1 List of Combustion Control Devices for Boiler

| Devices | Applicable boiler by fuel used | |
|---|---|---|
| | Oil-fired | Gas-fired |
| Water level gauge | x | x |
| Low water level cut-off device | x | x |
| Steam pressure gauge | x | x |
| Automatic water supply device | x | x |
| Water supply flow meter | x | x |
| Flame eye (flame detector) | x | x |
| Shut-off valve unit | x | x |
| Air pressure sensor | x | x |
| Pressure gauge after regulator | x | x |
| Oil supply flow meter | x | |
| Oil temperature gauge | x | |
| Oil pressure gauge | x | |
| Atomizing steam pressure gauge | x | |
| Gas pressure gauge after shut-off valve | | x |
| Gas pressure gauge at burner inlet | | x |
| Gas pressure limits switch | | x |
| Gas flow meter | | x |

The situation with regard to use of the above devices in ZMCM was analyzed for 94 boilers of 42 enterprises which answered the questionnaire : 11 boilers were diesel-fired, 50 were gas-fired and 33 were gasoil-fired.

"Enterprises" stand for mainly large to medium size factories and large non-industrial facilities. The data were in principle obtained through the synoptic survey with some exceptions that were obtained by the diagnostic survey. The result is summarized in Table 3.5.2.

Table 3.5.2 Situation of Use of Combustion Control Devices in Surveyed Enterprises

| Combustion Control Devices | Number of control devices | | | Installation rate of control devices (% ) | | | |
|---|---|---|---|---|---|---|---|
| | Diesel -fired | Gas-fired | Gasoil -fired | Diesel -fired | Gas-fired | Gasoil -fired | Avera -ge |
| Water level gauge | 11 | 48 | 30 | 100 | 96 | 91 | 95 |
| Low water level cut-off device | 11 | 47 | 26 | 100 | 94 | 79 | 89 |
| Steam pressure gauge | 10 | 48 | 31 | 91 | 96 | 94 | 95 |
| Automatic water supply device | 11 | 48 | 31 | 100 | 96 | 94 | 96 |
| Water supply flow meter | 0 | 32 | 15 | 0 | 64 | 45 | 50 |
| Flame eye (flame detector) | 11 | 46 | 23 | 100 | 92 | 70 | 85 |
| Shut-off valve unit | 7 | 47 | 29 | 64 | 94 | 88 | 88 |
| Air pressure sensor | 3 | 39 | 15 | 27 | 78 | 45 | 61 |
| Pressure gauge after regulator | 4 | 48 | 17 | 36 | 96 | 52 | 74 |
| Oil supply flow meter | 1 | - | 18 | 9 | - | 55 | 43 |
| Oil temperature gauge | 5 | - | 17 | 45 | - | 52 | 50 |
| Oil pressure gauge | 7 | - | 27 | 64 | - | 82 | 77 |
| Atomizing steam pressure gauge | 5 | - | 22 | 45 | - | 67 | 61 |
| Gas pressure gauge after shut-off valve | - | 49 | - | - | 98 | - | 98 |
| Gas pressure gauge at burner inlet | - | 49 | - | - | 98 | - | 98 |
| Gas pressure limits switch | - | 43 | - | - | 86 | - | 86 |
| Gas flow meter | - | 42 | - | - | 84 | - | 84 |

The situation of use of the combustion control devices is presented below:

1) Water Level Gauge, Low Water Level Cut-off Device and Automatic Water Supply Device

These devices are installed in order to avoid abnormal heating of combustion chamber and smoke ducts. The abnormal heating caused by the water level lower than the designed lower limit leads to damage of parts facing flame and smoke as deformation or, in more serious case, rupture. These devices work together to control the level of water contained in the boiler at a safe level.

Boilers equipped with all of these three devises are 87% of the total 94 boilers. However, gasoil-fired boilers show a relatively low installation rate at 76%. Considering the more urgent necessity of low-NOx operation for gasoil-fired boilers than for gas-fired and diesel-fired boilers, changes should be made so that this installation rate is increased, as quickly as possible.

2) Steam Pressure Gauge

This device indicates the pressure of the generated steam and informs if the pressure has reached an acceptable level for ignition of gasoil or other heavier oil, and if the pressure has exceeded or is about to exceed the designed safety level. This device is installed in almost all of the sampled plants.

3) Water Flow Meter, Oil Flow Meter and Gas Flow Meter

These flow meters are essential tools for knowing the boiler efficiency by use of measurement data for hourly water input and hourly fuel consumption. The dissemination of water flow meter was insufficient for oil-fired boilers; the rate of installation was 0% for diesel boilers and 45% for gasoil boilers, respectively. The installation rate of oil flow meters also was low. On the contrary, gas-fired boilers had an installation rate of the said measuring equipment at 84% or higher.

4) Flame Eye (Flame Detector) and Shut-off Valve Unit

The flame eye detects the existence of a flame formed by normal combustion. When it does not detect the flame, it conveys a signal to the fuel shut-off valve unit in order to terminate combustion immediately. This function is vital for safe operation because the continuous fuel supply to the combustion chamber during the absence of the flame can cause an explosion at the time of the following ignition. The installation rates of the flame eye and the shut-off valve unit on average are about 85% and 88%, respectively.

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

Appropiate combustion air pressure and fuel pressure are essential factors for proper combustion. Both are controlled in order to achieve efficient combustion or low-NOx combustion. Therefore, the oil pressure gauge and the gas pressure gauges (after shut-off valve and at burner inlet) are essential devices to control the combustion at an optimum state. The installation rates of the above devices are 61%, 74%, 77%, 98% and 98%, respectively. The air pressure sensor and the pressure gauge after regulator for oil-fired boilers show remarkably low installation rates. In particular, the installation rates are worst for diesel-fired boilers : only 27% for the air pressure sensor and 36% for the pressure gauge after regulator. Oil and gas pressure measuring devices are relatively widely installed.

6) Oil Temperature Gauge

This device is necessary for monitoring and adjusting the temperature of preheated oil fuels. Appropriate atomization of oil can be achieved under the condition of optimum oil temperature and optimum air-fuel mixing rate. The installation rate of this device is 50% on average and is still low.

7) Atomizing Steam Pressure Gauge

In case the steam is used as an atomizing medium for heavier oil, the pressure of steam affects the size of atomized oil particles. This device is necessary to achieve the optimum atomization in view of NOx reduction. The installation rate of the atomizing steam pressure gauge is 61% on average and is considered to be still low.

8) Gas Pressure Limits Switch

The pressure of fuel gas needs to be controlled within a safe range between a lower limit and a higher limit. This device works as a detector of gas pressure and conveys a signal to the shut-off valve unit in case the pressure goes below the lower limit or above the upper limit. The installation rate of the gas pressure limits switches is high, at 86%, but due to its vital function, further promotion of installation is still required.

(2) Ages of Boilers in ZMCM

Ages of boilers in ZMCM are generally old, and the average is found to be 20 years by the questionnaire survey. The distribution of age classes is presented in Figure 3.5.1. The age class with the largest number of boilers is 20-30 years (built between 1964 to 1973) with a share of 35%.

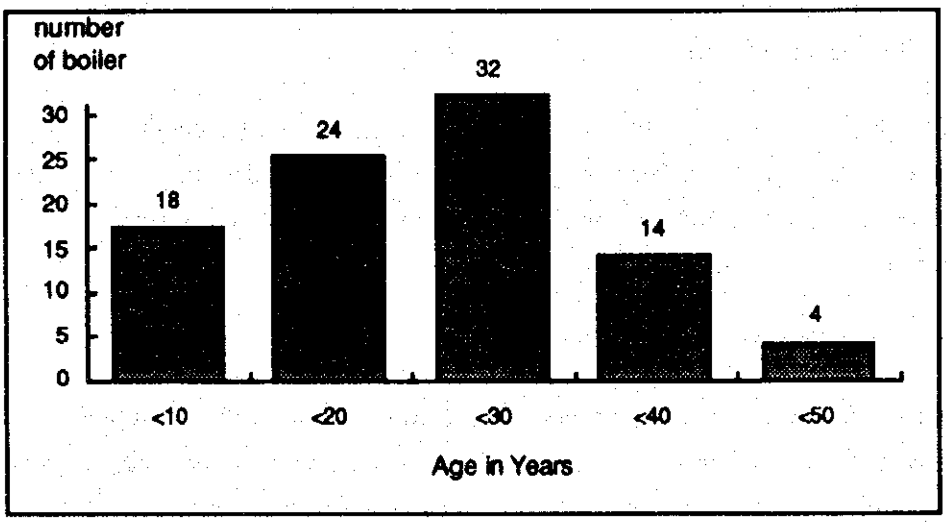


Figure 3.5.1 Distribution of Boiler Age

3.5.2 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. The loading rate naturally varies according to the production schedule and weather conditions. However, it was found that about half of the plants surveyed during the winter season of 1993/94 were operated with a load below 60% of the rated capacity. Such a trend is thought to be caused by : 1) old age of equipment that has lowered its performance, 2) weakness of the economy at the time, and 3) administrative measures requesting industries located in ZMCM to reduce the fuel consumption in order to prevent a winter crisis of air pollution.

Though it is sure that low load operation of combustion equipment contributes to mitigate air pollution, it results in lower combustion efficiency which is economically undesirable. The average boiler efficiency in México is approximately 60% according to CONAE, while the efficiency in Japan is usually guaranteed at 86% by boiler makers, and owners usually try to increase the efficiency.

High oxygen concentrations of exhaust gas were observed through the questionnaire survey and the diagnostic survey. For a total of 92 combustion facilities surveyed either by the questionnaire or the diagnosis, the $O_2$ content in exhaust gas was as shown in Table 3.5.3.

Table 3.5.3 $O_2$ Content in Exhaust Gas Surveyed by the Study Team

| Fuel | Combustion equipment | Pieces of equipment | $O_2$ concentration (%) | |
|---|---|---|---|---|
| | | | Range | Average |
| Diesel | boiler | 4 | 5.1 ~ 12.6 | 8 |
| | furnace | 2 | 2.5 ~ 11.0 | 7 |
| Gas | boiler | 33 | 2.1 ~ 10.2 | 5 |
| | furnace | 29 | 4.5 ~ 21.0 | 14 |
| Gasoil, heavy oil | boiler | 22 | 3.0 ~ 16.5 | 6 |
| | furnace | 2 | 6.5 ~ 14.3 | 9 |

Average $O_2$ content for the various types of equipment is 5% or more, and that of gas-fired furnaces is the highest at about 14%. Exhaust gases of furnaces tend to contain not only the combustion exhaust gas but also the air surrounding the materials processed. Therefore, the $O_2$ content of the exhaust gas from a furnace is influenced by the structure of the furnace, and is more difficult to control than that of the boiler exhaust gas. Among boilers, gasoil-fired boilers show higher $O_2$ content of exhaust gas in comparison to boilers burning diesel or gas. Because the largest part of heat loss in a combustion facility is the heat discharged through the smoke stack, the smaller the excess $O_2$ content, which is accompanied by nitrogen gas in the air four times as much as $O_2$ itself, the better for reducing the heat loss. The target control range of the $O_2$ concentration in exhaust gas is considered be $4 \pm 1$ % for boilers, based on the experience in Japan. It can be said that boilers in ZMCM have much room for reducing the exhaust gas $O_2$, particularly with those fired with gasoil or heavy oil.

(2) Situation of NOx Emission

The present situation of NOx emissions from stationary sources in ZMCM surveyed by the questionnaire and the diagnosis is summarized in Table 3.5.4. The table indicates the following characteristics.

1) Variation of NOx Concentration Reported in the Questionnaire

The answers for exhaust gas NOx concentrations were distributed in a range of zero ppm to more than 2,000 ppm. The high NOx concentrations are possible in the case 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 realize, except for the facilities using oxygen burners, unless the exhaust gas is diluted intentionally. Such doubtful data were reported for 16 facilities.

Table 3.5.4 NOx Concentration in Exhaust Gas Surveyed

| Fuel | Combustion equipment | Pieces of equipment. | Average NOx concentration (ppm) | Pieces of equipment exceeding present emission standard |
|---|---|---|---|---|
| Diesel | boiler | 2 (3) | 46 (105) | 0 |
| | furnace | 1 | 108 | - |
| Gas | boiler | 26 (12) | 89 (103) | 4 (1) |
| | heater, dryer, etc. | 10 | 66 | - |
| | furnace with high temperature | 12 | 620 | - |
| Gasoil, heavy oil | boiler | 12 (8) | 143 (121) | 1 (0) |
| | furnace with high temperature | 2 | 320 | - |

Note: 1) Data are based on the questionnaire survey and the diagnostic survey (the latter shown in parentheses).
2) Among the answers for NOx concentration data, abnormally low values such as 10 ppm or less are not taken into consideration.

The measurement results reported were generally prepared by consultants who were entrusted the measurements by the plant owners. Some of these data would have a certain question in reliability. However, the reported NOx concentrations of ordinary levels were not significantly different from those measured by the Study Team in the diagnostic survey.

2) Level of NOx Concentration

The exhaust gas NOx concentrations of boilers by fuel type vary from about 50 to 150 ppm on an average according to answers to the questionnaire, and those of gasoil or heavy oil-fired boilers were higher. As for individual plant data, the NOx concentrations for several boilers were found to be exceeding the present emission standard; this was the case for 4 among 26 of gas-fired boilers and 1 among 11 of gasoil or heavy oil-fired boilers. Out of 39 surveyed boilers, 8 boilers will not be able to comply with the new emission standards to be effective from January 1998 unless appropriate control measures are taken. But, these 8 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 boilers 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.

The NOx concentrations of industrial furnaces were about twice as much as those of boilers. But it is difficult to solve the problem due to their functional and structural requirements. The NOx reduction in these plants requires not only the introduction of low-NOx combustion technology but also a drastic change of the process or even relocation.

(3) Skill of Operators in Combustion Control

The skill in the operation of combustion equipment in México is certified by the Ministry of Labor and Social Welfare (STPS) in view of securing safe operation. The qualification is carried out through examinations for the applicants for the specific licenses such as operator (operador) and fireman (fogonero), and evaluation of educational records and job experience. According to the Regulation for Inspection on Steam Generator and High Pressure Vessels of México, boiler owners must assign the licensed personnel for the boiler operation.

Attainment of low NOx operation fundamentally requires skill in safe and energy-saving operation capability of all operators. Therefore, in practical terms qualified operators are thought to be more adaptable to undertake the low-NOx operation. To know the actual situation of assignment of qualified operators, the Study Team inquired of selected plant owners of the assignment of the licensed personnel. Among the surveyed enterprises, 41 are obliged to assign the licensed personnel under the law, and 12 enterprises have no obligation legally because they operate facilities other than boilers, such as furnaces, dryers, heaters, etc. The answers to the question if the enterprises assign any licensed personnel, are shown below classified by the status of the enterprises regarding the obligation to assign licensed personnel :

| | | |
|---|---|---|
| Those obliged to assign: | Total : | 41 enterprises |
| | Yes (assigning licensed person): | 38 enterprises |
| | No (not assigning): | 1 enterprise |
| | No answer : | 2 enterprises |
| Those not obliged to assign: | Total : | 12 enterprises |
| | Yes (assigning licensed person): | 4 enterprises |
| | No (not assigning): | 5 enterprises |
| | No answer : | 3 enterprises |

Out of the 41 enterprises which have an obligation to assign licensed personnel to boiler operation, more than 90% of them naturally answered "Yes", and only one enterprise answered "No". Even four enterprises which have no obligation are assigning licensed personnel for their equipment operation. Based on these survey results, the regulation by STPS is considered to be observed at large by relevant companies. The number of licensed persons assigned in the surveyed enterprises are shown in Table 3.5.5, by their qualification.

Table 3.5.5 Number of Licensed Operators Assigned in Surveyed Enterprises

| Status of enterprises | Number of licensed persons | Number of enterprises | | |
|---|---|---|---|---|
| | | Plant master (jefe de planta) | Operator (operador) | Fireman (fogonero) |
| Obliged to assign licensed operator | 1 | 2 | 8 | 7 |
| | 2 or more | 1 | 14 | 13 |
| | total | 3 | 22 | 20 |
| No obligation | 1 | 0 | 2 | 3 |

For the dissemination of the low-NOx combustion technology, development of the capabilities of persons licensed as plant master or operator is considered to be effective. They are considered to have sufficient experience and knowledge of safe operation, and therefore, have adaptability to low-NOx combustion technology.

### 3.5.3 Summary and Discussion

#### (1) Problem in Determining Boiler Load

Boiler loads confirmed by measuring fuel consumption rate by using a fuel flow meter or by other simplified means (measurement of storage tank level) in the diagnostic survey of factories are classified as follows.

| Boiler load | | |
|---|---|---|
| 80% or more | 2 plants | 2 boilers |
| 70-79% | 2 plants | 5 boilers (of which 4 are for power generation) |
| 60-69% | 3 plants | 3 boilers |
| 59% or less | 10 plants | 12 boilers |
| Unclear | 8 plants | 13 boilers |

As indicated above, the boiler load was not able to be determined for 37% of the boilers surveyed, because there were no means to determine the fuel and water consumption rates. Therefore, the evaluation of combustion status of these boilers in relation to the NOx concentration was not possible.

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

When the combustion load is considerably lower than the rated capacity, the NOx concentration of the exhaust gas also decreases. In the present emission standards of Mexico, the relationship between the NOx concentration and the boiler load is not clarified. Furthermore, the permissible CO concentration had been high at 250-400 ppm until December 1994, and since then the CO regulation 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. Many plants obviously did so when the Study Team conducted the survey. Since CO has a high NOx reducing effect, this practice can reduce the NOx concentration thereby meeting the emission standard. This means a loophole of the emission standard which allows intentional elusion from the regulation.

(3) Establishment of Measurement Certification System

At nearly all plants, mainly small or medium size plants other than those such as thermal power plants where automatic, continuous exhaust gas measurement system is installed, measurements of pollutant concentrations in exhaust gases are entrusted to private consultants. However, there is no certification system for measuring devices or standard gases owned by these private consultants. It was found that 2 or 3 enterprises were embarrassed by the reports of erroneous measurement data. The problem is serious to the extent that some of these enterprises were ordered by the government to reduce their operation rate greatly based on the submitted data, although the measurements were erroneous. Part of the problem may lie in the quality of work done by the measurement companies. Early legislation is needed for inspection and certification of measurement businesses including inspection of standard gases and the accuracy of measuring devices (zero drift, span drift, linearity, adsorption volume).

(4) Status of Switchover to Quality Fuels and Associated Problems

By the government decision made in December 1991, the supply of heavy oil was terminated in the spring of 1992, and it was replaced by natural gas, gasoil and diesel oil. The situation of combustion facilities concerning the fuel switchover is summarized below.

1) Switchover to Natural Gas

The result of the questionnaire survey indicated that the switch to natural gas progressed considerably. In the on-site survey conducted in 1990 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 of the 140 facilities owned by 47 companies, this ratio increased to 60%.

However, even though natural gas is used, 2 plants could not meet the current emission standards at the time of the survey: No.1 boiler (old 150 t/h boiler) of a power plant (Factory No.5) and three 45.4 t/h water-tube boilers of a paper factory (Factory No.13).

Combustion efficiency of the surveyed facilities was lower than the general average for natural gas burning. Since the combustion volume and the boiler load are low, it is inevitable that the combustion efficiency decreases to some extent. Nevertheless, the combustion efficiency should be improved by adequate combustion control measures so that it approaches the target of 90%.

2) Switchover to Gas Oil and Diesel Oil

The percentage of plants using liquid fuels is now 40%, a substantial drop from the time of the previous JICA study when heavy oil was used in large quantity. In these plants, diesel oil is used in only eight facilities (5.7% of the total), partly because of its high price.

Among those surveyed, one boiler exceeded the NOx emission standard. It is a 3.1 t/h smoke-tube boiler made by Company A installed in a chemical plant (Factory No.8). No. 5 smoke-tube boiler (7.8 t/h) also made by Company A used in a paper products factory (Factory No.7), did not exceed the emission standard, but came close to it. Boilers made by Company A generally exhibit good combustion efficiency. However, since the combustion chamber volume and the cross sectional area are small, the NOx concentration tends to become high when the combustion load reaches 70% or more of the rated capacity. Therefore, it is desirable to operate at a rate of 60% or less.

Factories that did not change either the burner nozzle or the tip when changing fuel from heavy oil to gasoil or diesel are as follows:

a) Petrochemical Products Factory (A) (Steam atomizing)

b) Petrochemical Products Factory (B) (Oil burner is not currently used except for emergencies, and natural gas is exclusively used.)

c) Thermoelectric Power Plant (A) (Oil burner is not currently used except for emergencies, and natural gas is exclusively used.)

d) Paper Products Factory (B) (Air atomizing of gasoil)

e) Alcoholic Drinks Factory (Only natural gas was burnt at time of measurement; oil burner was not used.)

f) Textile Factory (The plant side commented that they did not change either the burner nozzle or the tip because of the opinion of a consultant engineer.)

g) Paper Factory (C) (Plant side stated that the plant is outside the ZMCM and not subjected to the regulations applicable to ZMCM.)

h) Rubber Products Factory (C) (Air atomizing of diesel oil)

According to PEMEX and IMP, at the time of compulsory fuel switchover, seminars were held and warnings were given on several occasions in each district concerning the change of burner nozzles so as to prevent accidents and fuel wastage. Nevertheless, there seems to be a lack of observation of the official announcement since 8 of the 25 companies surveyed had not changed burner nozzles. The Study Team advised such change to the plants other than b), c) and e) above, where gas and oil had been used for mixed combustion before the fuel change but now only gas is burnt. At plants d) and h), in particular, caution and guidance are required since they use the boilers made by Company A whose boilers tend to generate NOx in high concentration, and the plants employ air atomizing.

(5) Inappropriate Combustion Due to Excessive Air

The combustion facilities operated at a exhaust gas $O_2$ concentration of 4% or less were only 14 or 10% of 140 combustion facilities surveyed by the questionnaire and 11 or 15.9% of 69 facilities surveyed in the diagnostic survey. The majority of the factories in ZMCM practice high excess air combustion, and more effort must be directed to energy saving. With medium or large scale boilers in which a recuperator is installed, the apparent $O_2$ concentration may become high depending on the sampling location. When the sampling is made after the recuperator, air intrusion into the recuperator may cause a high $O_2$ concentration. Except such cases and other special cases, it can be judged that operation control is inappropriate and fuel is wasted when the $O_2$ concentration at the exit of the combustion chamber is 4% or more. Further promotion of proper control of the air ratio by various means such as training seminars is necessary.

# CHAPTER 4 COMBUSTION TESTS

## Chapter 4 Combustion Test

### 4.1 Combustion Conditions in ZMCM

The elevation of the Metropolitan Zone of the City of Mexico (ZMCM) is about 2,240 meters above sea level. Therefore, the mass of oxygen per unit volume of air over the basin is only 77% of that at the sea level, although the volume ratio of oxygen in the air remains unchanged at 21%. Therefore, supply of a volume of air suitable for burning fuel at the sea level results in incomplete combustion at this height. In other words, complete combustion of unit mass of fuel in ZMCM requires 1.31 (i.e., 760 mmHg/580 mmHg) times the air volume necessary for the complete combustion at the sea level.

In the case of thermic rays anemometers calibrated at sea level, wind speed readings at the elevation of 2,400 m are 32% lower than those at sea level, in proportion to the difference in air density.

In recent years, automobiles sold in ZMCM have an air pressure sensor attached to the engine. Thus, the air/fuel ratio is automatically controlled in keeping with changes in altitude to prevent incomplete combustion. But up to the mid-1980s, the air/fuel ratio in automobile carburetors that had originally been adjusted for vehicle operation at sea level was not changed when the automobiles were then transported to ZMCM and sold. This further aggravated the air pollution in ZMCM.

The situation is similar in the case of various combustion facilities in stationary air pollution sources. When a boiler designed to be used at sea level is operated in ZMCM at the rated capacity, it requires 1.31 times the design volume of air, and the combustion chamber is completely filled with the flame and the chamber volume appears to be insufficient. Therefore, when such a boiler is to be used in ZMCM, a common knowledge calls for is to be used at 70% of the rated (maximum) capacity.

The altitude of the IMP laboratory at Pachuca City, where the combustion test in this Study was conducted, is about 2,400 m, and the atmospheric pressure is 570 to 580 mmHg (the average is 574 mmHg in August). The altitude is similar to that of ZMCM, and the volume of air required for combustion is 1.32 times that required at the sea level, being almost the same as in ZMCM. Accordingly, the draft fan for the test boiler was designed to provide 1.32 times the air volume which account for the total of pressure losses due to burner, boiler, etc. and the safety factor.

## 4.2 Outline of the Combustion Test Plant

### 4.2.1 Layout and Flow Sheet

The layout and the flow sheet of the combustion test plant are shown in Data Book.

### 4.2.2 Major Equipment

Major equipment in the combustion test plant is as follows.

(1) Boiler

| | |
|---|---|
| Name | Takao FTN-30 |
| Type | Flue and smoke-tube packaged type |
| Rated evaporation | 3.6 t/h |
| Rated heat output | $1.94 \times 10^6$ kcal/h |
| Rated pressure | 10 $kg/cm^2$ |
| Normal pressure | 7 $kg/cm^2$ |
| Heat transfer area | 49.6 $m^2$ |
| Steam temperature | Saturation temperature (normal 169 °C) |
| Feed water temperature | 20 °C |
| Combustion method | Pressurized down flow 3-pass combustion |
| Combustion chamber | Morison wave once-through flue type |
| Combustion chamber dimension | Diameter: 0.95 m (min.), 1.06 m (outer)<br>Length: 3.40 m |
| Combustion chamber volume | 2.409 $m^3$ |
| Rated volumetric load of combustion chamber | $926 \times 10^3$ kcal/$m^3$/h |
| Method of boiler control | |
| Steam pressure main control | Proportional control of burner combustion (air and fuel) with pressure detection |
| Range of proportional control | 20 - 100 % load (depending on burner specification)<br>On-off control below 20 % load |
| Water level control | On-off control with electrode type water level detector |
| Drum diameter | 1,924 mm |
| Boiler length | 4,500 mm (including front and rear smoke chambers) |
| Draft system | Forced draft system |

(2) Water Softener

| | |
|---|---|
| Softening method | Ion exchange method |
| Treatment capacity | 5 $m^3/h$ |
| Volume of resin | 600 liter |

(3) Chemical Feeder

| | |
|---|---|
| Injected volume | 60 mℓ/min. |

(4) Soft Water Tank

| | |
|---|---|
| Capacity | 4.2 $m^3$ |

(5) Continuous Blow-off Device

| | |
|---|---|
| Type | Feed water ion exchange type |
| Water blow-off rate | 600 ℓ/h |
| Water supply rate | 8 $m^3/h$ |

(6) Silencer

| | |
|---|---|
| Capacity | 3,000 kg/h |
| Standard sound attenuation | 65 dB or less at 10 m |

(7) Economizer

| | |
|---|---|
| Type | ECG type with heat-resistant glass tube |
| Rated capacity | 3.6 t/h |
| Heat recovery rate | 103,000 kcal/h |
| Heat transfer tube | 50 mm (diameter) x 3.2 mm (thickness) |
| Heat transfer area | 22.6 $m^2$ (glass tube) |
| Effective length | 720 mm X 200 pieces |

(8) Steam Heat Type Air Heater

| | |
|---|---|
| Exchanged calorific value | 108,000 kcal/h |
| Materials | SUS 304 |

(9) Electric Suction Heater

For storage tank and service tank of fuel oil

(10) Oil Transfer Pump (with Strainer)

Transfer from storage tank to service tank

(11) Fuel Pump Unit

Heavy and light quality oil 2 distributed type with strainer and oil heater

(12) Automatic Combustion Control Unit (full-automatic proportional control)
One each for oil combustion and natural gas combustion

(13) Boiler Relay Box

(14) Boiler Control Panel
For combustion facility control

(15) Automatic Water Supply Control Unit

(16) Forced Draft Fan (with Silencer Case)

| | |
|---|---|
| Type | Turbo-vane, one-side suction, cantilever bearing, direct connection to motor |
| Air flow | 87.5 $m^3$/min (at 20°C) |
| Revolution | 3,510 r.p.m |
| Bulk density of gas | 0.916 kg/$m^3$ (at 20°C and 580 mm Aq) |

(17) Feed Water Pump

| | |
|---|---|
| Type | Vertical multi-stage turbine pump |
| Capacity | 5.1 t/h x 110 m, 4.0 kw |

(18) Feed Water Injector

(19) Feed Water Flow Meter and Oil Flow Meters (for preheating oil and gas oil)

(20) Compressor

| | |
|---|---|
| Maximum pressure | 7 kg/$cm^2$ |
| Air discharge | 1,250 ℓ/min. |
| Air tank capacity | 32 ℓ/min. |
| Revolution | 1,000 r.p.m. |

(21) Duct for Exhaust Gas Recirculation
With control damper

(22) Steam Header

(23) Steam Warmer (for 200 l drum can)

| | |
|---|---|
| Vapor pressure (normal) | 5 kg/$cm^2$G |
| Heat transfer area | Drum: 1.24 $m^2$, Bottom: 0.24 $m^2$ |

(24) Normal Oil Burner (With Steam Atomizer)

| | |
|---|---|
| Atomizing method | Air or Steam (changeable) |
| Mixing method | Inner mixing |

| | |
|---|---|
| Combustion capacity | 240 kg/h |
| Atomizing oil pressure | 3.5 kg/cm$^2$ at burner inlet |
| Atomizing steam pressure | 4.5 kg/cm$^2$ |
| Atomizing steam consumption | 3.5 kg/h |
| Viscosity of oil at burner inlet | 20 cSt or less |

(25) Low-NOx Oil Burner (No. 1)

| | |
|---|---|
| Type | Self-recirculation/reducing combustion |
| Atomizing method | Steam (air for cold start) |
| Mixing method | Inner mixing |
| Combustion capacity | 240,000 kcal/h |
| Atomizing oil pressure | 5.0 kg/cm$^2$ or more |
| Atomizing steam pressure | 4.0 kg/cm$^2$ or more |

(26) Low-NOx Oil Burner (No. 2)

| | |
|---|---|
| Type | Self-recirculation/two-stage combustion |
| Atomizing method | Steam (air for cold start) |
| Mixing method | Inner mixing |
| Combustion capacity | 240 kg/h |
| Atomizing oil pressure | 4.0 kg/cm$^2$ |
| Atomizing steam pressure | 5.0 kg/cm$^2$ |
| Viscosity of oil at burner inlet | 20 cSt or less |

(27) Low-NOx Oil Burner (No. 3)

| | |
|---|---|
| Type | Two-stage combustion |
| Atomizing method | Steam (air for cold start) |
| Mixing method | Inner mixing |
| Combustion capacity | 240 kg/h |
| Atomizing oil pressure | 6.0 kg/cm$^2$ or less at burner inlet |
| Atomizing Steam pressure | 4.5 kg/cm$^2$ or less at burner inlet |
| Viscosity of oil at burner inlet | 20 cSt or less |
| Primary/secondary air ratio | 70 % /30 % (when dampers are full open) |

(28) Normal Gas Burner

(With safety control devices including flame eye, upper and lower limits switch and gas shut-off valve)

| | |
|---|---|
| Combustion capacity | 2.45 x 10$^6$ kcal/h |
| Gas pressure at burner inlet | 0.2 kg/cm$^2$ |

(29) Low-NOx Gas Burner

(With safety control devices including flame eye, upper and lower limits switch and gas shut-off valve)

| | |
|---|---|
| Type | Self-recirculation combustion |
| Capacity | $2.45 \times 10^6$ kcal/h |
| Gas pressure at burner inlet | 0.5 Kg/cm$^2$ |

(30) Oil Pump for Drum Can

| | |
|---|---|
| Diameter | 40 mm |
| Head | 20 m |
| Pumping capacity | 18 l/min. |

(31) Duct

(32) Stack

(33) Storage Tanks and Service Tanks for Gas Oil and Diesel

| | |
|---|---|
| Capacity of storage tank | 8 m3 x 2 |
| Capacity of service tank | 1.2 m$^3$ x 2 |

(34) Exhaust Gas Treatment Device (Fan Scrubber)

| | |
|---|---|
| Fan scrubber | |
| Processing gas capacity | 100 m$^3$/min. |
| Revolution | 2,000 r.p.m. |
| Materials (gas contacting section) | SUS 316 |
| Circulation wash pump | |
| Pump discharge | 0.55 m$^3$/min. |
| Materials (liquid contacting section) | SUS 316 |
| Mist separator | |
| Quantity of injected water(mist separator) | 300~450 ℓ/min. |
| Materials (exhaust gas and liquid section) | SUS 316, SUS 316L |

(35) Exhaust Gas Treatment Device (Recirculating Device)

pH controller

Power driver filter

Compressor

Electronic density meter

Pump for Alkali

Circulation pump

Stirrer

(36) Automatic Flue Gas Monitoring System

| | |
|---|---|
| Sampling probe | SUS 316 10μ filter<br>Temperature control type |
| Heated sampling tube | 20 m Teflon Tube<br>Temperature control type |
| Pretreatment unit | Teflon filter, with dehumidifier |
| Automatic NOx analyzer | Pressure reduced chemiluminescense, With $NO_2 \rightarrow NO$ converter, Range (0-50, 0-100, 0-250, 0-500, 0-1,000 ppm) |
| Automatic $SO_2$ analyzer | Non-dispersive infrared absorption<br>Range (0-1,000, 0-5,000 ppm) |
| Automatic CO analyzer | Non-dispersive infrared absorption<br>Range (0-1,000, 0-2,000 ppm) |
| Automatic $CO_2$ analyzer | Non-dispersive infrared absorption<br>Range (0-10, 0-20 %) |
| Automatic $O_2$ analyzer | Zirconia sensor type<br>Range(0-0.5, 0-5, 0-10, 0-25 %) |

(37) Data Processing Device and Data Processing Software

| | |
|---|---|
| Personal Computer | 32 bit, 486sx, RAM 4MB, HD 84MB,<br>3.5 inch FDD x 1 |
| Monitor | 14 inch color display |
| Printer | 24 dot matrix method |
| A/D converter | 12 bit, 32 channel |
| Software | ANACOMP4 |
| Recorder | 12 channel, dot type |

## 4.3 Outline of the Combustion Test

### 4.3.1 Fuels and Burners Used

(1) Fuels

Fuels used for the combustion test are as follows :

- Gas oil (including the varying N content)
- Diesel oil
- Gas oil with addition of residual carbon

The specifications of gas oil and diesel for Lot No.1 presented by IMP are shown in Table 4.3.1. Results of analyses by the Study Team are shown in Section 4.4.5.

Table 4.3.1 Specifications of Diesel Oil and Gas Oil (Lot No.1)

| Item | Unit | Diesel Oil | Gas Oil |
|---|---|---|---|
| Specific gravity (20/4) | °C | 0.8455 | 0.8860 |
| Flash point | °C | 117 | 131 |
| Pour point | °C | -6 | -12 |
| Kinematic viscosity (40°C) | cSt | 4.11 | 9.66 |
| Kinematic viscosity (60°C) | cSt | 2.68 | 5.44 |
| Lower calorific value | BTU/LB (kcal/kg) | 18,319 (10,177) | 18,153 (10,085) |
| Residual carbon (Rams bottom method) | W/W% | 0.07 | 0.23 |
| Water and Residue | V/V% | <0.05 | 0.20 |
| C | W/W% | 85.95 | 85.59 |
| H | W/W% | 13.46 | 12.56 |
| O | W/W% | 0.10 | 0.10 |
| S | W/W% | 0.47 | 1.57 |
| N | W/W% | 0.028 | 0.075 |
| Ash | W/W% | 0.00018 | 0.0006 |
| Insoluble matter (C5) | W/W% | <1 | <1 |
| Na | μg/g | 0.95 | - |
| Ni | μg/g | <0.02 | - |
| V | μg/g | <0.5 | - |

(2) Burners

The burners used for the combustion test are as follows:

- Normal oil burner: The burner which forms 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 the reducing combustion.
- Remodeled low-NOx oil burner

### 4.3.2 Test Items and Methods

(1) $O_2$ Concentration in Exhaust Gas

The simplest method of low-NOx combustion is to lower the concentration of residual $O_2$ in exhaust gas. The combustion tests were conducted under the following 4 levels of $O_2$ concentration:

$O_2$% at initial smoke or CO generation
3%
5%
7%

Of these percentages, 5% is the standard concentration of $O_2$ stipulated in the emission standard of NOx in Mexico. 7% is the concentration found at many of the plants where the diagnostic survey was conducted. In reporting the combustion test results, measured NOx concentration values were converted to the values at the standard $O_2$ concentration of 5% unless otherwise indicated.

(2) Examination of Optimum Atomizing Conditions

1) Combustion Temperature

a) Diesel oil: Room temperature

b) Gas oil: Initially, tests were conducted at room temperature. But because there were large quantities of suspended materials in the oil, the nodes of the oil pump strainer frequently became clogged. Accordingly, when the fuel heating unit prepared by the Mexican side was completed, the temperature of the pump unit was raised to 45 to 55 °C.

2) Nozzle Angle

The angle of the burner nozzle was changed within the range of 50 to 75° depending on the burner structure, and the effect on NOx concentration was investigated.

3) Atomizing Medium

Tests were made of NOx concentration with respect to air atomization and steam atomization both of which are widely used in Mexico City.

(3) Effect of Preheated Air Temperature on NOx

Recovery of the heat from the exhaust gas into combustion air is a common method of conserving energy. But as the temperature of combustion air increases, the NOx concentration also increases. In this test, a steam air preheater was used, and the NOx concentration was investigated under three conditions of the combustion air temperature: room temperature, 80 to 100 °C, and approx. 150 °C.

(4) Effect of Combustion Load on NOx Concentration

Tests were conducted at 50%, 70% and 90% of the rated load in order to investigate the influence of the volumetric and the cross sectional loads of the boiler on the NOx concentration. Accordingly, tests were conducted at the following fuel consumption rates: 120 l/h, 160 l/h, and 200 l/h.

(5) Effect of Nitrogen Content of Fuel on NOx Concentration

The conversion rate of nitrogen in fuel to NOx increases as the nitrogen content in the fuel decreases, and decreases as the nitrogen content increases. Triethylenetetramine (TETA) was added to gas oil by IMP to provide oil samples of varying nitrogen content for the combustion tests. Analysis of nitrogen content for each sample was made by the Study Team and IMP separately by the different methods.

(6) Energy Saving and NOx Concentration

In addition to the steam air preheater, as previously mentioned, this test plant has an economizer as a mean to recover the waste heat, both being common energy saving equipment. Boiler efficiency was measured when each of these units was operated, and the corresponding relationship with the NOx concentration was examined. A continuous boiler water blow-off device of the heat recovery type was also installed aiming at transfer of energy saving technology.

(7) Exhaust Gas Recirculation (EGR) Test

Exhaust gas recirculation (EGR) is one of the effective measures for reducing NOx concentration. But when the nitrogen content in fuel increases, the rate of NOx reduction by EGR decreases thereby losing its effectiveness. In this test, diesel oil and gas oils with varying content of nitrogen were used to investigate the effectiveness of EGR on the reduction of NOx by comparing the data with that obtained without employing EGR.

(8) Steam Injection Test

In this test, steam was injected into the boiler and the effect on the NOx concentration was investigated.

(9) Remodeling of Normal Oil Burner

Self recirculation function of the low-NOx oil burner (1) is considered to be relatively easily incorporated into normal burners. In order to investigate the possibility of improving existing burners in Mexico City, a self-recirculation device was attached to the normal oil burner and the performance in NOx reduction was tested.

4.3.3 Measuring Items and Methods

(1) Items and Methods Pertaining to Exhaust Gas

| | | |
|---|---|---|
| CO | : | Non-dispersive infrared absorption |
| $CO_2$ | : | Non-dispersive infrared absorption |
| $SO_2$ | : | Non-dispersive infrared absorption |
| $O_2$ | : | Zirconia method |
| NOx | : | Reduced pressure chemiluminescence |
| Dust | : | Bacharach smoke tester and Ringelman method |
| Exhaust gas velocity | : | Pitot tube |
| Exhaust gas temperature | : | Thermoelectric coupling |

Using a sampling probe and a sampling tube heated to 150 °C, the exhaust gas is channeled to a gas pretreatment unit to remove drain and the moisture content, then directed to each analyzer.

(2) Measurement Items Pertaining to Combustion Control

Oil flow rate
Oil temperature
Gas flow rate
Gas temperature
Gas pressure
Steam flow rate
Atomizing steam pressure
Atomizing oil pressure

| | | |
|---|---|---|
| Economizer | : | Inlet gas temperature, outlet gas temperature, inlet feed water temperature, feed water outlet temperature |
| Air preheater | : | Inlet air temperature, outlet air temperature |

Combustion efficiency (by combustion efficiency meter)

### 4.3.4 Time Stage for the Test

Time stages for equipment installation and functional examination, combustion tests, and fuel analysis are as follows.

(1) Equipment Installation and Functional Examination

1) Equipment Installation (July 1 to August 5)

In parallel to the works of foundations, wiring, piping, and water supply by the Mexican side, installation of various equipment units sent by JICA was carried out under the on-site guidance of the Study Team members.

2) Equipment Operation Tests (August 8 to August 11)

Installed equipment was turned on, and examinations were made on motor revolution, switch function, hardness of softened water, etc., and necessary calibrations were made.

3) Boiler Pressure-proof Test (August 12)

The pressure-proof test was conducted by filling the boiler with water, and raising the pressure to the prescribed value of 16 kgf / $cm^2$.

4) Burner Ignition, Boiling with NaOH Solution, and Cleaning of Boiler Interior (August 15 to August 16)

The ignition test of the normal oil burner was conducted using diesel oil, and boiler functions were confirmed. Then NaOH solution was boiled to remove oils and impurities from the boiler interior. Before the ignition, the oil feed pipe was cleaned and tested for pressure-proofness.

5) Confirmation of Functions of Boiler Safety Control Devices (August 17)

With Mexican counterparts in attendance, each of the safety control devices was checked for correct function at standard settings. The devices checked were the safety valves, the low water level cut-off device, the low water level alarm, the oil pressure drop switch, the flame detector, the atomizing pressure drop switch, and the blower trip breaker. Then, the adjusters for the safety valves were locked.

(2) Combustion Test

1) Tests with the Normal Oil Burner (First Time, August 18 to August 19)

Diesel oil was used to conduct tests so that the participants would become familiar with the test equipment.

2) Tests with Low-NOx Oil Burner (1) (First Time)

a) August 22 to August 24
Burner replacement
b) August 25 to August 27
Tests with diesel oil
c) August 29 to September 5
Tests with gas oils with varying content of nitrogen prepared by IMP
d) September 6
Boiler efficiency measurement

3) Tests with Low-NOx Oil Burner (2)

a) September 7 to September 8
Burner replacement
b) September 8
Tests with diesel oil
c) September 9 to September 16
Tests with gas oils with varying content of nitrogen

d) September 19

Primary air/secondary air volume measurement

e) September 20 to September 27

Tests with gas oils with varying content of nitrogen

f) September 28

Boiler efficiency measurement(efficiency during operation of economizer and air heater)

4) Tests with Normal Oil Burner (2nd Time)

a) September 29 to September 30

Burner replacement

b) October 3 to October 13

Tests with gas oil with varying content of nitrogen (inner mixing type atomizer used)

c) October 6, October 15, October 17 and October 18

Boiler efficiency measurement (efficiency during operation of economizer and air heater by varying oxygen concentration in exhaust gas)

d) October 19 to October 21

Exhaust gas recirculation test

Diesel oil, gas oils with varying content of nitrogen

e) October 22 to October 28

Tests by atomizing steam pressure

Atomized with outer-mixing type atomizer using diesel oil and gas oils with varying content of nitrogen (inner-mixing type atomizer used on October 27)

f) November 3 to November 4

Tests by atomizing steam temperature (diesel oil and gas oil used)

g) November 7 to November 10

Tests with gas oils with varying content of residual carbon

h) November 11 to November 14

Remodeling of the normal oil burner

5) Tests with Low-NOx Oil Burner (1) (2nd Time)

a) November 14

Burner replacement

b) November 15 to November 26

Tests for reducing combustion

6) Low-NOx Oil Burner (3)

a) November 29
Burner replacement

b) November 30 to December 6
Tests for low-NOx combustion by adjusting amounts of the primary and secondary air. To realize complete reducing combustion in the primary combustion chamber, the ratio of the primary air amount to the theoretical amount was set to 0.4 - 0.9.

7) Normal Gas Burner

a) December 7
Burner replacement and preliminary tests
Since the insufficient capacity of the regulator on the gas pipeline and the wastes in the pipeline prevented the gas supply, the test with natural gas was discontinued.

b) December 8
With Mexican counterparts in attendance, the interlocker for natural gas combustion was tested.

8) Remodeled Low-NOx Burner

a) December 9 to December 11
Installation and adjustment of the remodeled burner

b) December 12 to December 14
Tests with gas oil

c) December 15
Restoration of the remodeled burner to the normal type

9) Maintenance (December 16 to December 20)

Maintenance of the boiler, accessories, and flue gas monitoring equipment, etc.

(3) Analysis of Fuel Samples

Samples of fuels provided by IMP for the combustion test were analyzed.

a) August 16 to August 24
Preparation of equipment for analysis

b) August 25 to November 30
Analysis of samples