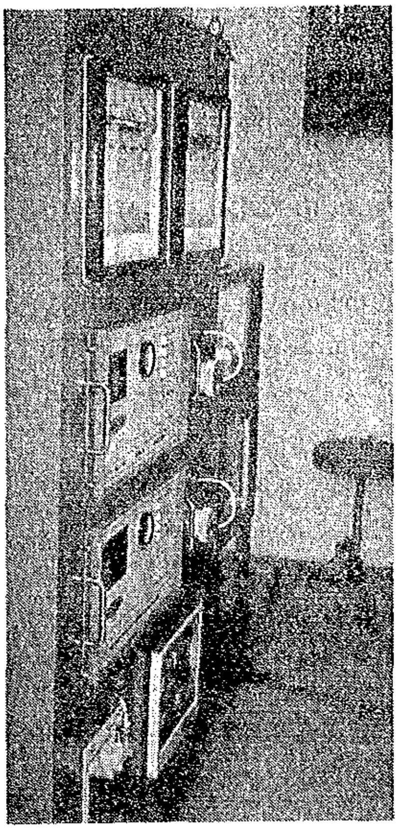
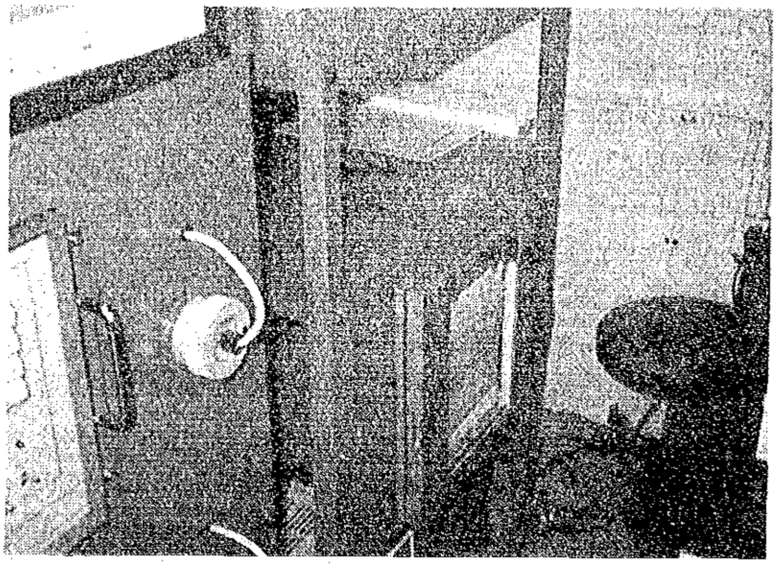
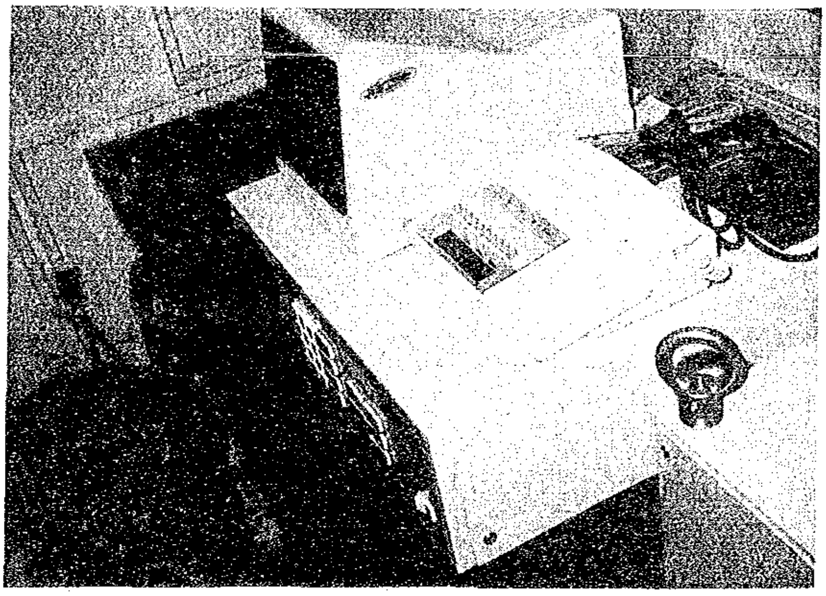




Two dimensional ultrasonic anemometer recording part

SO_2 , NO_x and particulate measuring instruments



Data logging terminal

Photo 2-3 (2) Snapshots of MS2 station

(3) Mineral Department Office (MS3)

This office is located in Phra Pradaeng county, 4.6 km away from and to the northwest of South Bangkok Power. The eastern end of the office faces Chao Phraya river and the west side of the building commands a canal 120 m apart. The station, MS3 was placed in a corner of the park within Mineral Department site. The area has Bangkok Steel Industry on the other side of Chao Phraya river at a distance of 2.4 km to the west and Ajinomoto (Thailand) 600 m to the south.

The traffic volume of the vicinity roads is small, but 700 m apart to the north-north-east of the station there are ferryboat terminals for shuttling service across Chao Phraya (in term of boats, 1,300 boats per day). Furthermore, Chao Phraya river itself has the traffic volume of 150 boats per day, in size ranging between several hundreds up to 10,000 or more in tonnage.

Suksawat road (Route 303) runs with daily traffic volume of 55,000 vehicles at 1 km apart from and to the west-south-west of the station MS3. The air quality was measured by instruments placed in MS3. Photo 2-4 are snapshots taken in the vicinity of MS3.

MS 3

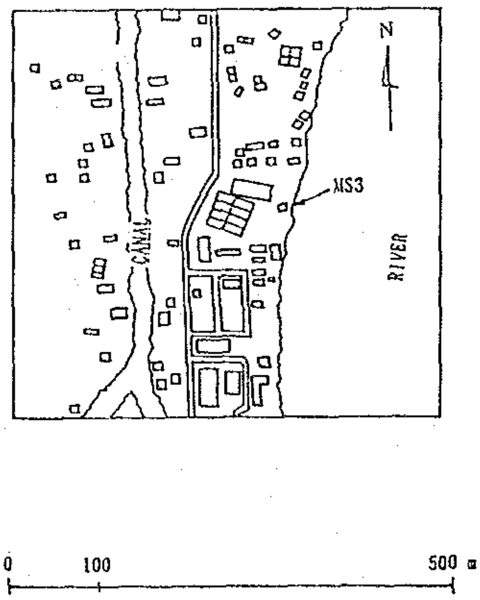
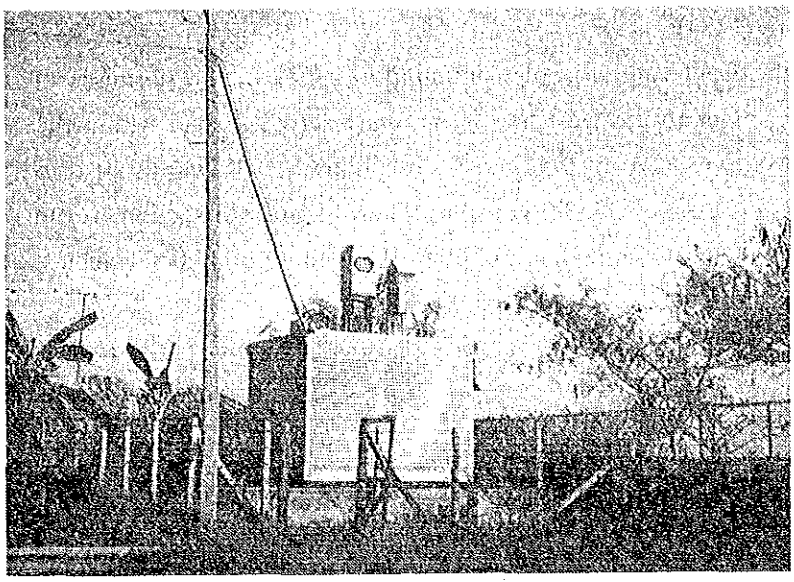
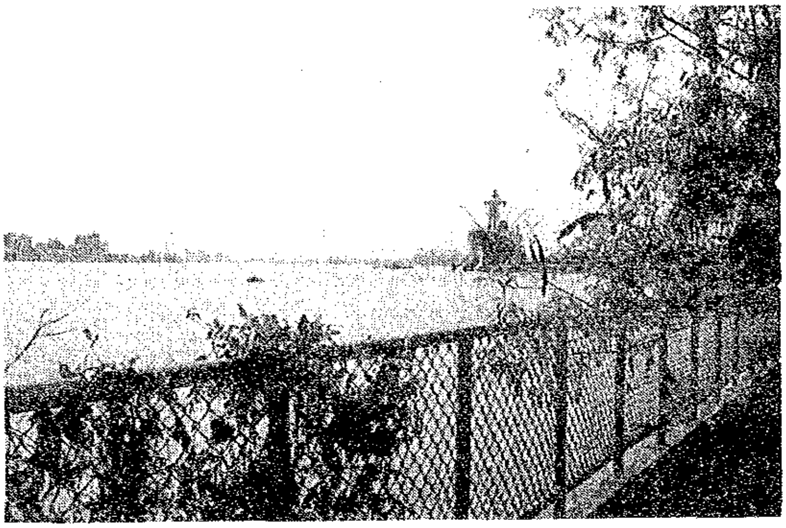


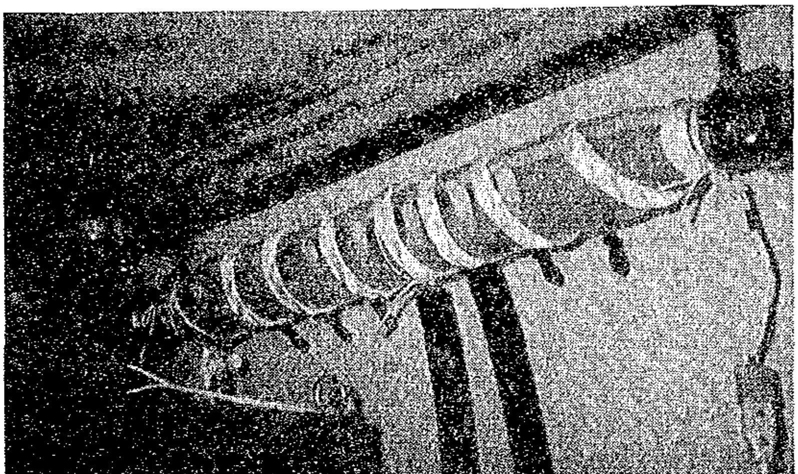
Figure 2-5 The area map of MS3



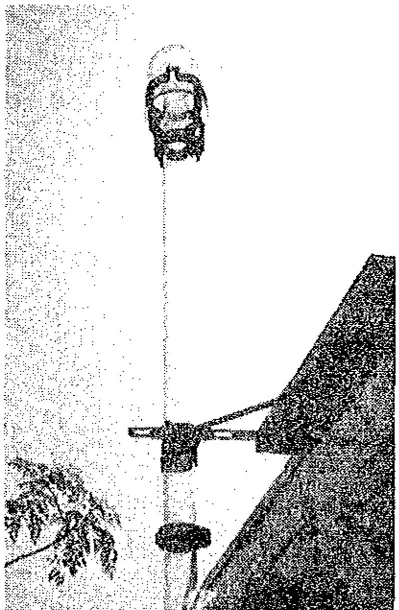
The external appearance of MS3



Chao Phraya river viewed from MS3



A manifold traced by the ribbon heater



Air intake

Photo 2-4 Snapshot of MS3 station

(4) Provincial Office of Samut Prakarn (MS4)

The station MS4 was placed at the front gate side of Community Center in the premises of provincial office and has Chao Phraya river to the west and 30 m apart across a road within the premises. To the east of MS4, however, as shown in Figure 2-6, SuKhumvit road (Route 3) runs about 90 m apart from MS4 with daily traffic of 35,000 vehicles. There is an intersection to the north-north-east of MS4 and about 200 m apart, which has a daily traffic volume of 47,000 vehicles. There exists no factory in the neighborhood of MS4.

The air quality was measured by instruments placed in MS4. Photo 2-5 shows some of snap-shots of the MS4 area.

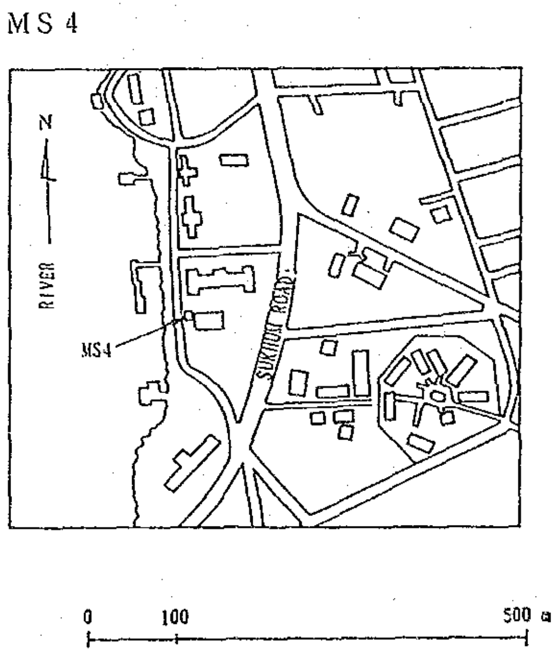
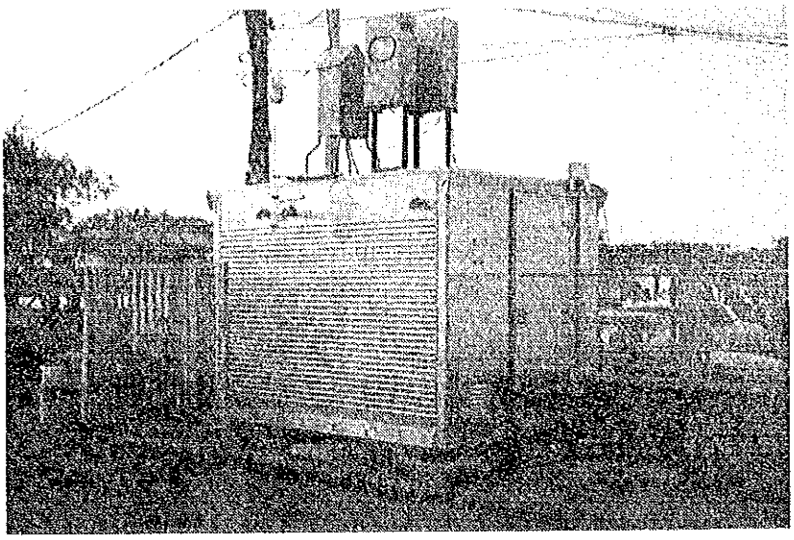
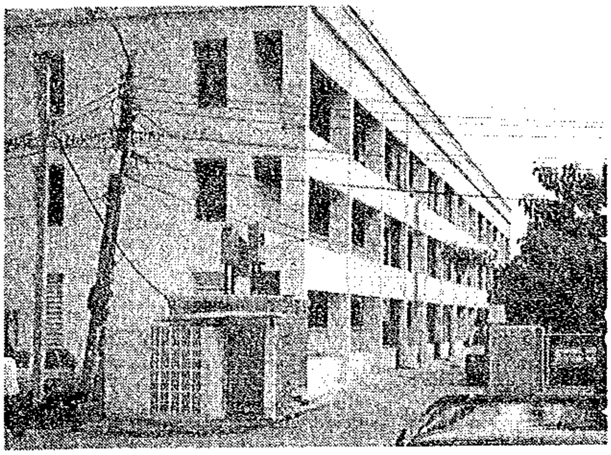


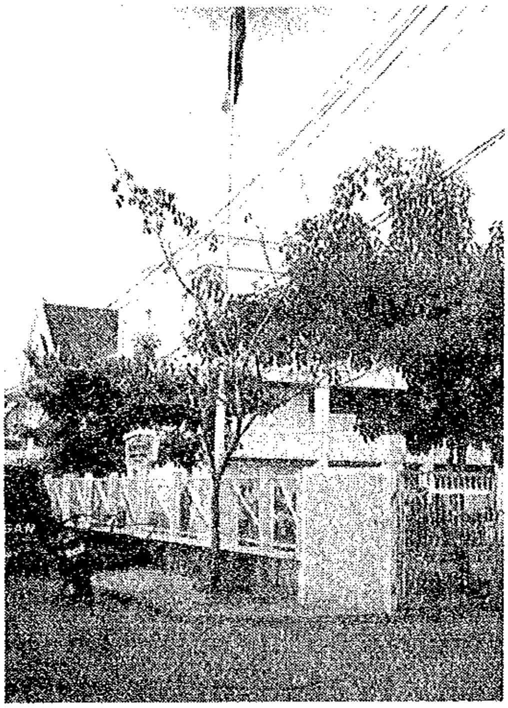
Figure 2-6 The area map of MS4 station



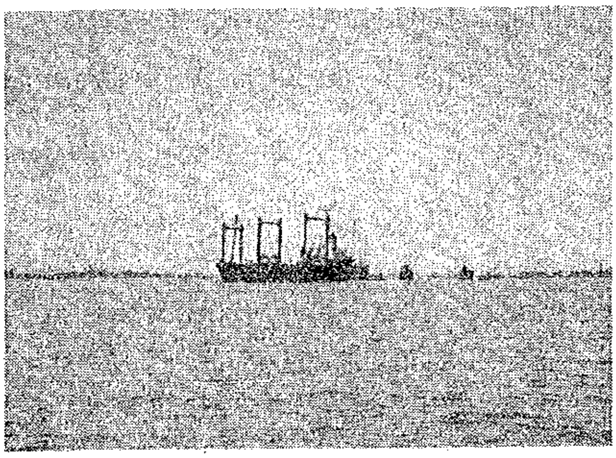
The external appearance of MS4



MS4 viewed from the front gate of the community center



Samut Prakarn Provincial Office



Chao Phraya river viewed from MS4

Photo 2-5 Snapshots taken from MS4 spot

(5) Housing and Industrial Estate office (MS5)

The station MS5 was placed within the premises of Housing and Industrial Estate office of Bang Plee county. The area is basicly a grassland and has scattered shops and houses to the south of MS5 and at a distance of 60 m as shown in Figure 2-7 or has a non-developed housing site to the further south.

There is the Industrial Estate office to the east of MS5 and 150 m apart across a lane leading to Thepharak road (Route 3268), which is non-paved. The spot where MS5 is placed has no factory in its neighborhood but has, to the south and 1.3 km apart, Bangna-Trat Highway (Route 34) with daily traffic of about 32,000 vehicles.

The air quality was measured by instruments placed in MS5 and the wind speed as well as direction was by an anemometer mounted on a pole 10 m high. Photo 2-6 shows the neighborhood views snapshotted.

MS 5

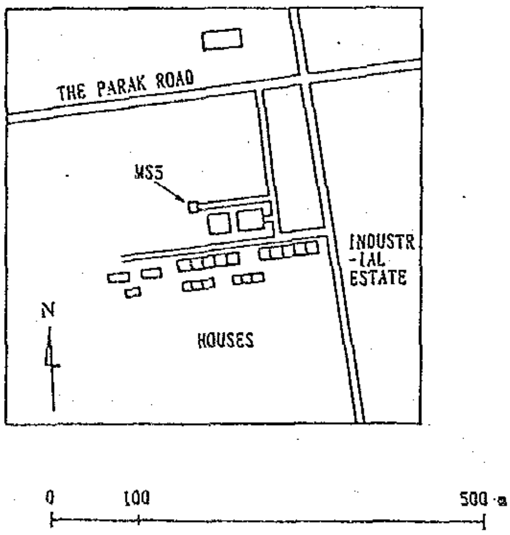
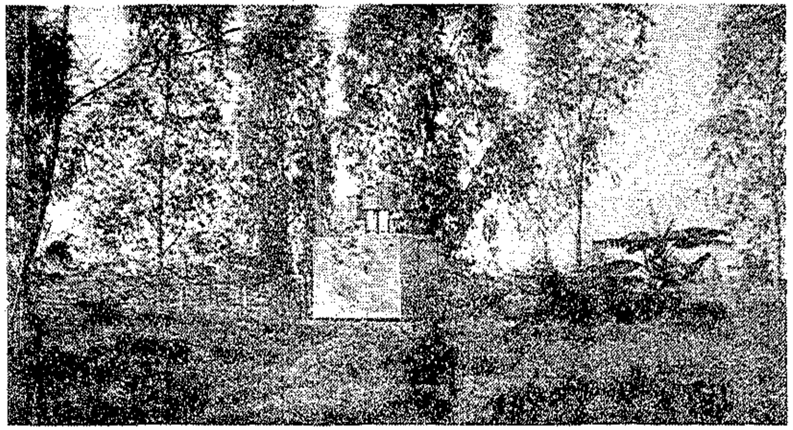
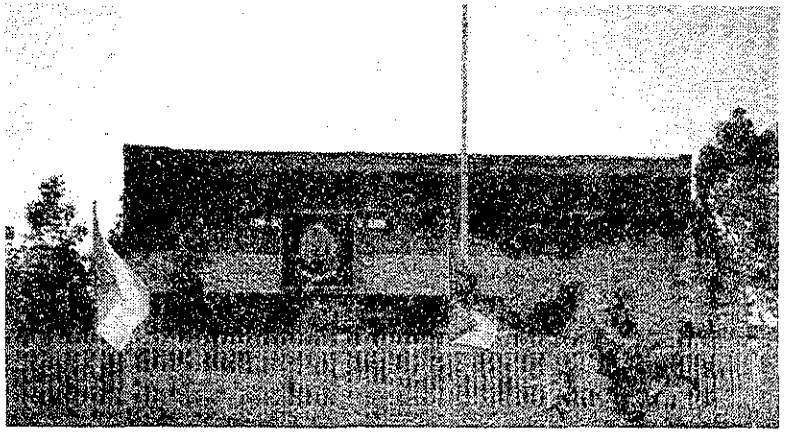


Figure 2-7 The area map of MS5

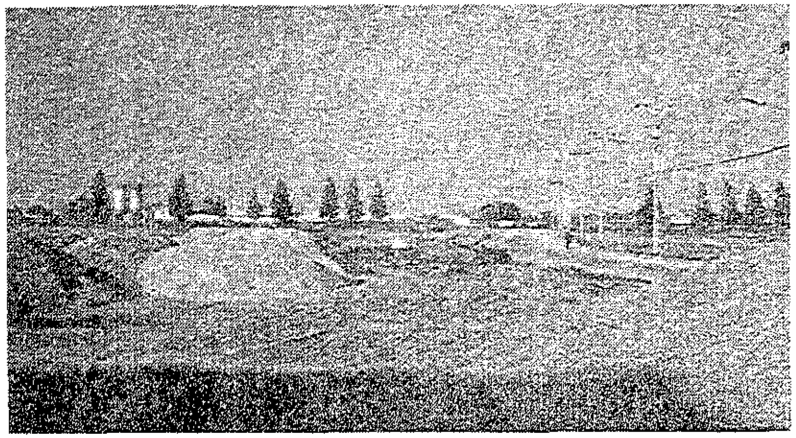


The external appearance of MS5 station

Housing and Industrial Estate office of Bang Plee county



Two dimensional ultrasonic anemometer fixed at a 10 m high pole top



The industrial site viewed from MS5

Photo 2-6 Snapshots taken from MS5 spot

3. Education and training relevant to handling of measuring instruments

The field survey, as aforementioned, is dependent on instruments of automatic and continuous type to complete a year round monitoring of such variables as SO_2 and wind velocity. Thus the maintenance of those instruments was thought of utmost importance to assure the accuracy of measurements throughout such a long period. The job was basicaly arranged such that ONEB is responsible for the regular inspection and maintenance of instruments and the Japanese staff team for the periodical check and part replacement of them.

Under the circumstances, it was decided that ONEB staff engineers receive the training course with respect to basic theories involved, handling, maintenance and calibration of applied instruments. The training was also practiced from the viewpoint that those instruments can be operated by Thai staff members even after the completion of this project.

The technical transfer cooperation with respect to instruments handling was made three times in total each at the first, second and third field trip by Japanese staff. As for periodical inspection and maintenance of instruments, the transfer cooperation was made when 1st, 2nd, 3rd and 4th Japanese survey team practiced the scheduled checks on instruments. The persons who received such training and the content of transfer cooperations are listed as follows.

(1) Handling, maintenance and calibration of instruments

The first field survey period

Mr. Warawut Suadee	Environmental Officer
Mr. Kanok Suksomsunk	ditto
Mr. Khunchai Kriengkrai-udom	ditto
Mr. Santad Koompalum	ditto

The second field survey period

Mr. Warawut Suadee
Mr. Kanok Suksomsunk
Mr. Khunchai Kriengkrai-udom
Mr. Santad Koompalum
Mr. Suphol Cheiwkijkachorn

The third field survey period

Mr. Warawut Suadee
Mr. Kanok Suksomsunk
Mr. Khunchai Kriengkrai-udom
Mr. Santad Koompalum
Mr. Suphol Cheiwkijkachorn

(2) Scheduled inspection and maintenance of instruments

The first survey period

Mr. Warawut Suadee
Mr. Khunchai Kriengkrai-udom
Me. Santad Koompalum

The second field survey period

Mr. Warawut Suadee

Mr. Khunchai Kriengkrai-udom

Mr. Santad Koompalum

The third field survey period

Mr. Warawut Suadee

Mr. Khunchai Kriengkrai-udom

Mr. Santad Koompalum

The fourth field survey period

Mr. Warawut Suadee

Mr. Khunchai Kriengkrai-udom

Mr. Santad Koompalum

Mr. Phunsak Tiramongkol

Mr. Kanok Suksomsunk

The outline of technical transfer efforts such as handling of instruments, etc is as follows. It is described more in detail in the succeeding chapter with respect to each monitoring target.

3.1 The technical transfer related to instrument handling

The first effort of such technical transfer was made immediately after the monitoring station structure was built and the measuring instruments were brought in and placed in it.

The way of operation and handling of instruments were taught through practical drills and then by means of instruction manuals written in English and prepared in advance. After measurements started, Japanese staff checked together with ONEB staff the condition of instruments and readings once every hour according to the check manuals. As for Low volume samplers as well as Andersen samplers, all of them were temporarily assembled in an ONEB room and were subject to calibration while technical transfer relevant to such job being made. Then samplers were transported to each of stations where the result of training at ONEB was again reconfirmed.

From the second field survey on, the technical transfers continued in such a way that both Thai and Japanese parties coworked in the adjustment and calibration of instruments. An activity snap is shown in Photo 3-1.

3.2 Technical transfer about scheduled inspection and maintenance

The transfer cooperation was made four times with respect to the scheduled inspection and maintenance of instruments.

(1) SO_2 meter

1) Replacement and adjustment of lamp unit
2) Cleaning of detector window
3) Cleaning of measuring cell
4) Replacement of detector window
5) Alignment of optical axis
6) The way of inspection of I/O and CPU board when sensitivity is dropped

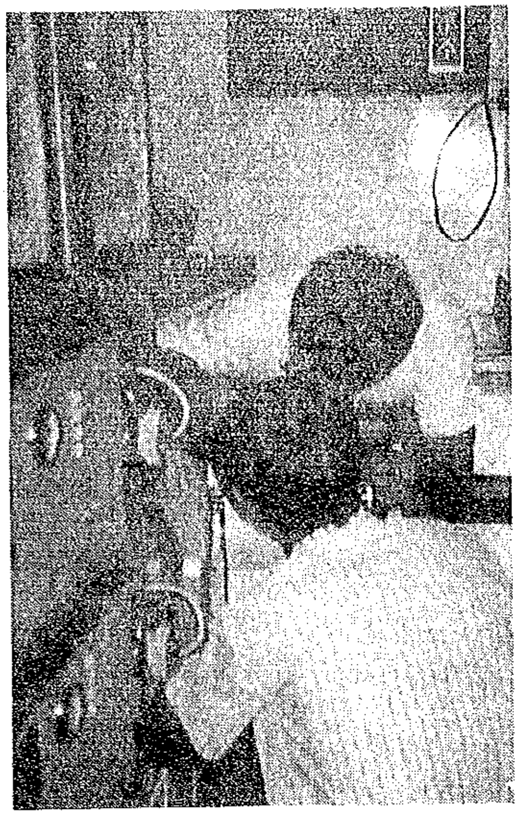
(2) NO_x meter

1) Cleaning of cell window
2) Replacement of photomultiplier
3) Cleaning of detector interior
4) Inspection method of dark current of detector
5) Voltage measurement of O_3 generator power source
6) The way of inspection of I/O and CPU board when sensitivity is dropped.

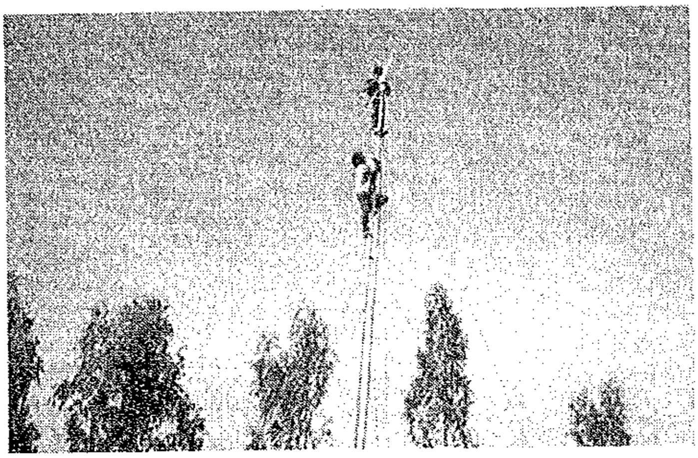
(3) β-ray adsorption type dust meter

1) Cleaning of cell
2) Precaution relevant to β-ray source
3) Adjustment of flow stabilization circuit
4) Cleaning of dust trap
5) The way of inspection of I/O and CPU board

SO_2, NO_x and dust meter being explained



Two dimensional ultrasonic anemometer being explained



Two dimensional ultrasonic anemometer being adjusted

Three dimensional ultrasonic anemometer being explained

Photo 3-1 (1) Technical transfer interactions snapshotted


Radiation and radiation balance meter being explained


Data logger being explained


Low volume sampler being calibrated


Low volume sampler and Andersen sampler being explained

Photo 3-1 (2) Technical transfer interactions snapshotted

4. Long term field survey (1 year survey)

A year long field survey continued for the period of January 17, 1988 through January 16, 1989 to measure an hour averages of SO_2 , NO, NO_2, SPM, wind speed and direction, air turburency, solar radiation and radiation balance by using respective instruments. The measurement data were typed out in hard copies and were simultaneously transmitted to a data logger and a telemetric printer installed at ONEB central supervisory and control room. (The data observed by MS1 station, however, were not transmitted to ONEB.)

In addition to data collection above, total suspended particulate were monitored by low volume sampler at each station, where two samplers were installed, one with a polyfluorocarbon filter to improve the accuracy of elemental as well as ion analysis and the other with a quartz filter for carbon analysis of the dust.

The filters of sampler were replaced once every half a month and trapped particulate matters were subject to analyses throughout the survey period.

Table 4-1 summarizes the type of measurements practiced at every station.

Table 4-1 The type of measurements practiced at MS1 through MS5 for the longterm field survey period

Observation		Measurements	Instruments
MS1	ONEB Station	Sulphur dioxide (SO_2)	Ultraviolet-spectrophotometry
		Nitrogen oxides (NO, NO_2)	Chemiluminescence NO_x meter
		Suspended particulate matter	β-ray adsportion type meter
		Total suspended particulate (TSP)	Low volume sampler
		Wind velocity and direction	3-dimensional ultrasonic anemometer
		Air turbulency	ditto
		Solar radiation	Eppley pyrheliometer
		Net radiation flux	Net radiation flux meter
MS2	Power plant (EGAT)	SO_2	Ultraviolet Spectro-photometry
		NO, NO_2	Chemiluminescence NO_x meter
		SPM	β-ray adsorption type meter
		TSP	Low volume sampler
		Wind velocity and direction	2-dimensional ultrasonic anemometer
MS3	Mineral Department Office	SO_2	Ultraviolet Spectrophotometry
		NO, NO_2	Chemiluminescence NO_x meter
		SPM	β-ray adsorption type meter
		TSP	Low volume sampler
MS4	Samut Prakarn Provincial Office	SO_2	Ultraviolet Spectrophotometry
		NO, NO_2	Chemiluminescence NO_x meter
		SPM	β-ray adsorption type meter
		TSP	Low volume sampler
MS5	Housing & Industrial Estate Office	SO_2	Ultraviolet Spectrophotometry
		NO, NO_2	Chemiluminescence NO_x meter
		SPM	β-ray adsorption type meter
		TSP	Low volume sampler
		Wind velocity and direction	2-dimensional ultrasonic anemometer

4.1 Measurement of environmental pollutant concentrations

4.1.1. Measurement of SO_2 atmospheric concentration

In order to monitor the status quo of SO_2 pollution in Samut Prakarn Industrial District, the SO_2 measuring instruments of automatic and continuous type were placed at five stations and pollutant concentrations were measured once every hour continuously throughout one year survey period. The instruments were subject to the calibration once every week and also to the scheduled inspection, once every three months.

(1) SO_2 environmental concentration measurement

There are several measurement methods proposed for the measurement of SO_2 + SO_3 as shown in Table 4-2. Among these, methods of (1) through (4) are described in Japanese Industrial Standards (JIS) as continuous monitor of environmental SO_2 concentration. In addition, the methods of (2) through (4) and (9) are described in Federal Register of EPA (U.S.A.) as continuous monitor and the method (9) as standard one for manual analysis. The method (1) is employed as one to judge whether the measured value meets the national control standards stipulated.

Table 4-2 Measuring methods of ambient sulphur oxides

	Measuring methods	Pollutants	Applicable conc. range	Relative standard	Remarks
(1)	Solution conductmetry	SO_2	0 - 50 ppb, 0 - 1 ppm	JIS B7952	Continuous analyzer
(2)	Coulometry	SO_2	0 - 100 ppb, 0 - 1 ppm	JIS B7952	- ditto -
(3)	Flame photometric	SO_2	0 - 100 ppb, 0 - 1 ppm	JIS B7952	- ditto -
(4)	Ultraviolet spectro-photometry	SO_2	0 - 100 ppb, 0 - 1 ppm	JIS B7952	- ditto -
(5)	Chronoamperometry	SO_2	0 - 100 ppb, 0 - 1 ppm	JIS B7952 Reference	- ditto -
(6)	Lead dioxide	SO_2 + SO_3	Over 0.2 SO_3 mg/ d/100 cm2	B.S.1747 Part 15 ASTM D.2010	Relative conc. measurement
(7)	Alkali filter	SO_2 + SO_3	Over 0.2 SO_3 mg/ d/100 cm2	-	- ditto -
(8)	Valium molybdate	SO_2 + SO_3	-	-	Chemical analysis
(9)	Pararosaniline	SO_2	3 ppb - 5 ppb	ASTM C.2914	Continuous & Chemical analysis

(2) Methods used in this survey

The type of analyzer used in this survey is of Ultraviolet spectro-photometry type, which uses the fluorescence light emitted from the sulphur dioxide in the ambient air brought into the excited state, SO_2^*, by absorbing ultraviolet ray. The SO_2 concentration is determined by measuring the fluorescence intensity. The reactions to show this principle are shown as follows,

$SO_2 + h\nu 1 = SO_2^*$ ....(4-1)

$SO_2^* = SO_2 + h\nu 2$ ....(4-2)

$SO_2^* = SO + (O)$ ....(4-3)

$SO_2^* + M = SO_2 + M$ ....(4-4)

where the reaction (4-1) indicates that a SO_2 molecule absorbs the UV energy $h\nu 1$ and goes into the excited state, SO_2^*, the reaction (4-2) the excited molecule emitting light energy $h\nu 2$ when it returns to the ground state, the reaction (4-3) decomposition of the excited molecule by light and the reaction (4-4) the excited molecule losing its energy by colliding with other molecules (called quenching).

In general, when SO_2 molecules are irradiated by a UV ray, absorption occurs in the following three wavelength bands as shown in Table 4-3 and Figure 4-1 in which band 1 and band 2 are weak in adsorption and show a large trend for quenching. Therefore, the band 3 with the largest absorption and the least quenching trend is selected as excitation light by means of a selection filter. The fluorescence light of excited SO_2 is detected through the optical selection filter. Since the hydrocarbons in the air also emit fluorescence, they are normally removed by using an HC cutter (scrubber).

Table 4-3 Ultraviolet ray adsorption bands of SO_2

Bands	Wavelength
1	390-340 nm
2	320-250
3	230-190

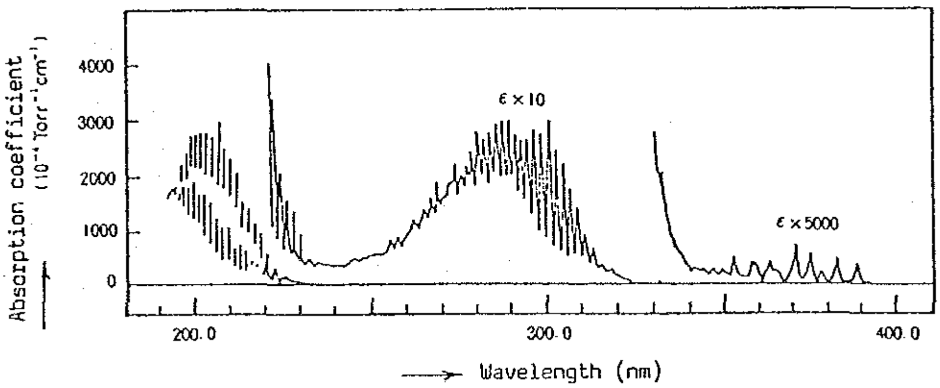


Figure 4-1 Adsorption spectrum of SO_2

The SO_2 analyzer used in this survey is an ultraviolet-spectro-photometry one, manufactured by DKK Corporation, GFS-31 type. The analyzer is designed such that it can introduces the internally refined zero gas into the cell once every 20 minutes and stabilizes the zero point level by comparing the zero gas value with the sample value. The light source lamp is of pulse-driven type and thus reading is taken during the pulse lightening period of the lamp in order to minimize the effect of dark current of a photomultiplier tube. The mechanism is thought effective to prolong the service life of the lamp too.

The recording part of the system reads both instantaneous and hourly averages and has external I/O terminals and an external output connector to transmit hourly averages to the data logger as well as telemetric recorder.

As for hourly averages, the automatic range switcher is built in and changes the range from a smaller one to a next larger one when reading exceeds the scale range (0–0.05 ppm, 0–0.1 ppm, 0–0.2 ppm, 0–0.5 ppm, 0–1.0 ppm). When reading newly starts, the range gets automatically back to 0–0.05 ppm one.

Major specifications of this SO_2 analyzer are shown in Table 4-4, the measurement system diagram in Figure 4-2 and the mechanical structure in Figure 4-3.

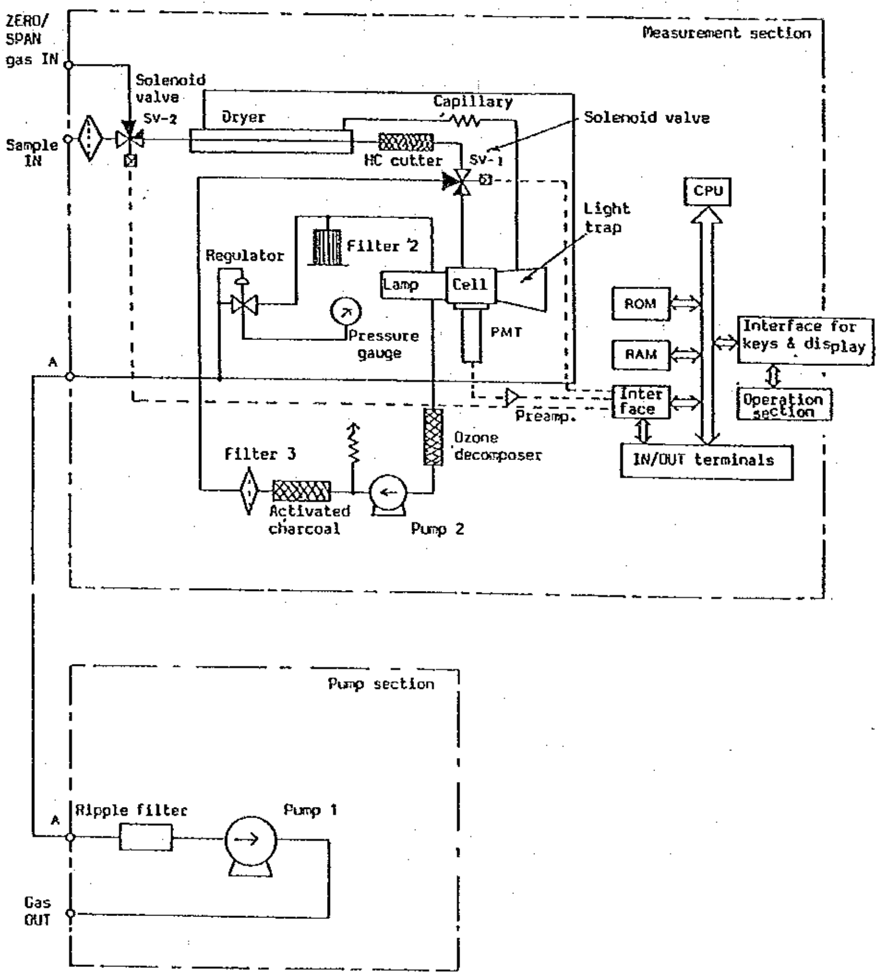


Figure 4-2 Measurement system diagram

Table 4-4 Major specifications of SO_2 analyzer

Name of product:	Atmospheric sulfur dioxide analyzer
Model:	GFS-31
Measurement object:	Atmospheric SO_2
Measurement method:	Continuous measurement on the principle of ultraviolet fluorescence
Measurement range:	Instantaneous value 0-0.1, 0-0.2, 0-0.5, 0-1.0 ppm, manually switched 4 ranges Hourly average (Saw-tooth) 0-0.05, 0-0.1, 0-0.2, 0-0.5, 0-1.0 ppm, automatically switched 5 ranges
Display:	Instantaneous value of SO_2
Reproducibility:	Within ± 2%FS
Stability: Zero drift	Within ± 1%FS/day
Span drift	Within ± 2%FS/day
Response time:	Within 4 minutes for 90% response
Ambient temperature:	0-40℃
Power requirements:	100VAC± 10%, 50/60Hz
Power consumption:	150VA
Dimensions:	Measurement section 430(W)x596(D)x270(H) mm Pump section 270(W)x285(D)x280(H) mm
Weight:	Measurement section 23kg Pump section 6kg
Color painting:	Munsell N4 and N7
Input/output signals:	<u>Transmission output</u> 0-1VDC (isolated input), instantaneous value and hourly average, (Max.internal resistance 500Ω , min. load resistance 100kΩ) <u>Contact output signals</u> o Instantaneous value measurement range switching signal o Hourly average value measurement range switching signal o Under-adjustment (TEST) signal o Blown-fuse signal o Under-calibration signal o Calibration-impracticable signal (Contact rating 50VDC 0.1A or less) <u>Contact input signals</u> o External reset signal o Observatory stop signal o Auto-calibration start signal (Contact rating 50VDC 0.1A or less)
Related equipment:	Data printer Analog recorder Cubicle for outdoor installation

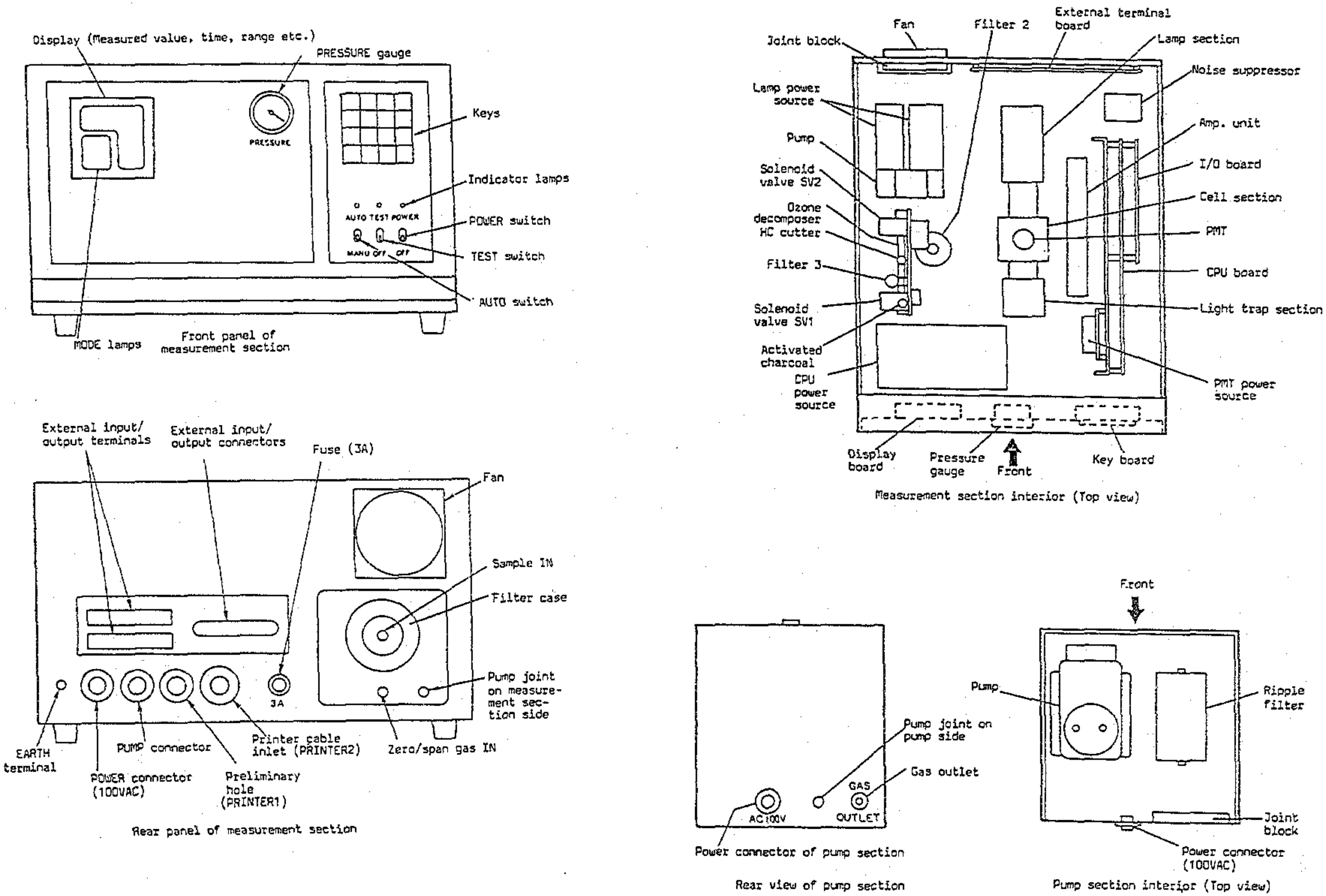


Figure 4-3 The mechanical structure of SO_2 analyzer

(3) Operation

The analyzer is put into operations by actuating front panel keys (see Figure 4-3) in which the selection of operation mode leads the operator to various options like calibration, time setting, etc. The detail of key operations conforms to Japanese or English manuals.

Table 4-5 (1) Key operations of SO_2 analyzer

Operation item		Key operation procedure
(1) Time	Setting	[TIME] [RF [illegible]] [ENT] Press the entry key when the present time agrees with the registered figures.
	Reading	[TIME] [ENT] ([C] depression for releasing. Display returns to concentration.)
(2) Zero gas introduction		[ZERO] [ENT] ([C] depression for releasing.)
(3) Span gas introduction		[SPAN] [ENT] ([C] depression for releasing.)
(4) Span setting value	Writing	[SPN V] [RF [illegible] *] [ENT] * Span gas concentration
	Reading	[SPN.V] [ENT] ([C] depression for releasing.)
(5) Automatic calibration time	Writing	[CAL.T] [RF [illegible]] [ENT] (Returns to concentration indication after 1 second.)
	Reading	[CAL.T] [ENT] ([C] depression for releasing.)
(6) Automatic calibration period	Writing	[PER.] [RF [illegible]] [ENT] (Returns to concentration indication after 1 second)
	Reading	[PER] [ENT] ([C] depression for releasing.)
(7) Number of remaining days till next calibration	Writing	[CAL.D] [RF [illegible]] [ENT] (Returns to concentration indication after 1 second.)
	Reading	[CAL.D] [ENT] ([C] depression for releasing.)
(8) Automatic calibration starting		[STA] [ENT] (With AUTO switch in AUTO position.)
(9) Measurement range	Switching (Writing)	Instantaneous value [RANG] [CONC] [RF] [ENT] (RF : 0.1, 0.2, 0.5, 1.0)
		Average value [RANG] [AVG] [RF] [ENT] (RF : 0.05, 0.1, 0.2, 0.5, 1.0)
	Reading	[RANG] [CONC] [ENT] or [RANG] [AVG] [ENT]

Table 4-5 (2) Key operations of SO_2 analyzer

<table>
<tr><th>Operation item</th><th>Key operation procedure</th></tr>
<tr><td>(10) Transmission test</td><td>Instantaneous value [.] [RF 000~010] [1] [ENT] (With TEST switch in ON position)
Average value [.] [RF 000~010] [4] [ENT]

Registered figures in transmission test<table><tr><td>Registered figures</td><td>000</td><td>001</td><td>002</td><td>…</td><td>010</td></tr><tr><td>Output voltage(mV)</td><td>0</td><td>100</td><td>200</td><td>…</td><td>1000</td></tr><tr><td>Indication</td><td>0</td><td>100</td><td>200</td><td>…</td><td>1000</td></tr></table></td></tr>
<tr><td>(11) Zero point rise</td><td>Instantaneous value [.] [RF .300~.310] [ENT] (To release, press [.] [3] [0] [0] [ENT])

Registered figures for zero rise of instantaneous value<table><tr><td>Registered figures</td><td>.300</td><td>.301</td><td>.302</td><td>…</td><td>.310</td></tr><tr><td>Raised graduation</td><td>0</td><td>1</td><td>2</td><td>…</td><td>10</td></tr></table>
Average value [.] [RF .320~.330] [ENT] (To release, press [.] [3] [2] [0] [ENT])

Registered figures for zero rise of average value<table><tr><td>Registered figures</td><td>.320</td><td>.321</td><td>.322</td><td>…</td><td>.330</td></tr><tr><td>Raised graduation</td><td>0</td><td>1</td><td>2</td><td>…</td><td>10</td></tr></table></td></tr>
<tr><td>(12) Coefficient reading</td><td>Span coefficient [.] [4] [1] [1] [ENT] .... a
Automatic calibration zero correction amount [.] [4] [1] [5] [ENT] I
Automatic calibration span coefficient [.] [4] [1] [6] [ENT] .... J</td></tr>
<tr><td>(13) Coefficient writing</td><td>Automatic calibration zero correction amount [.] [4] [7] [5] [ENT] [RF -0.05~+0.05] [ENT]
([CALO] key serves as the negative sign key.)

Automatic calibration span coefficient [.] [4] [7] [6] [ENT] [RF 0.8~1.1] [ENT]</td></tr>
</table>

(4) Calibration

Though the GFS-31 SO_2 analyzer has a provision for automatic calibration capacity, the job was manually done in this survey. The procedures of calibration are the connection of calibration supply gas system with SO_2 meter, and then calibration of zero gas and span gas by means of the key panel on the front operation side of analyzer. The standard gas used was one cylindered with about 90 ppm in SO_2 content, pre-inspected by Chemicals Inspection & Testing Institute, Japan. Since the guarantee term of this standard gas is a half year period, it was replaced in the middle of survey period.

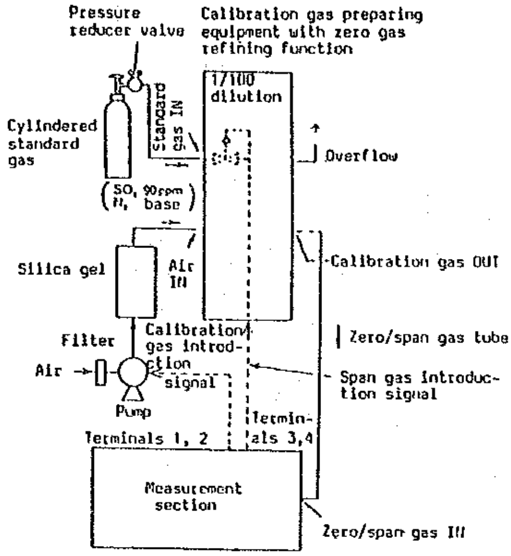


Figure 4-4 The supply system of calibration gas

(5) Inspection and maintenance

In order to maintain the desirable performance of the SO_2 meter, the inspections were practiced as shown in Table 4-6, in which weekly and monthly periodical inspections and calibrations depended on ONEB and others were performed jointly by ONEB and Japanese staff.

Table 4-6 Scheduled inspection items of SO_2 analyzer

	Objects of maintenance check: Object		Item	Contents	Check period: Week	Month	3 months	6 months	Year	Reference Section
1	Flow path tubings		Check	Fouling, buckling, disconnection, leak		○				
			Replacement	Each tube					□	
			Leak	Leak test			○			
2	Filter case	Element(PF)	Replacement	Replacement by new one.	□					7.2
		Case	Cleaning	Joints, filter case interior			△			
3	Glass element of measurement section		Cleaning	Glass element			△			7.3
			Replacement	Replacement with new one					□	
4	Suction pump in pump section		Check	Abnormal sound, vibration		○				
				Is pressure normal ?	○					
			Cleaning	Diaphragm, valve, joint			△			7.4
			Replacement	Replacement of diaphragm and valve by new one.					□	
5	HC cutter replacement		Replacement	Replacement by new one.			□			7.5
6	Activated charcoal replacement		Replacement	Replacement by new one.					□	7.5
7	Ozone decomposer replacement		Replacement	Replacement by new one.					□	7.5
8	Light source lamp replacement		Replacement	Replacement by new one.					□*	7.6
9	Cell		Cleaning	Cell wall					△	7.7
10	Calibration		Calibration	Manual zero/span	○					5.1
11	Clock		Check	Check for time deviation	○					4.1 e.
12	Capillary		Cleaning	Internal cleaning				△		
			Replacement	Replaement by OKK genuine parts					□	
13	External tubings		Check	Fouling, buckling, disconnection, leak	○					2.3
			Replacement	Replacement by new one.					□	
14	Wiring with outside		Check	Loosening, breakdown	○					2.4

* 2 years

○ : Check for abnormality. Perform the specified work. Adjust to specified values.
△ : Clean the specified place.
□ : Replace designated parts for maintaining the performance.

(6) Measurements

Table 4-7 summarizes the effective measuring hours except those spent for calibration as well as equipment troubles. The figures at all measuring points are thought longer than a guideline figure required for the effective monitoring station in Japan, i.e., 6,000 hours (cumulative).

Table 4-7 Effective measuring hours of atmospheric SO_2 concentration

Station	Effective measurement (hours)	Availability(%)
MS1	8,684	98.9
MS2	8,515	96.9
MS3	8,502	96.8
MS4	8,562	97.5
MS5	7,225	82.3

(Remark: Total hours for Jan. 17, 1988 through Jan. 16, 1989 is 8,784 hrs.)

The causes of trouble that each monitoring station had were listed in Table 4-8 together with measured variables. Among them, the largest downtime in case of SO_2 measurement, was caused by the dew drop formed inside the manifold and brought into the instrument. The troubles in photomultiplier and power failure follow as second and third largest single reason respectively.

Table 4-8 The causes of instrument downtime during the long term survey

	Missing cause	SO_2	SPM	NO	NO_x
MS-1	For calibration	48	13	63	59
	For maintenance	13	7	11	11
	Electric power out	38	35	44	49
	Over-current				
	Outlying value				
	Calibration error			49	49
	Maintenance error				
	Poor indication				
	Temperature rise by air-conditioning				
	Water condensation of manifold				
	Out of order of air-conditioning				
	Mechanical trouble by water		23		
	Mechanical trouble	1	307	53	56
	Total	100	385	225	224
MS-2	For calibration	57	23	56	56
	For maintenance	16	10	15	15
	Electric power out	164	134	140	140
	Over-current				
	Outlying value		3		
	Calibration error	8		467	584
	Maintenance error				
	Poor indication		1		
	Temperature rise by air-conditioning			21	21
	Water condensation of manifold		126		
	Out of order of air-conditioning			49	49
	Mechanical trouble by water				
	Mechanical trouble	24	68	156	156
	Total	269	365	904	1021
MS-3	For calibration	33	9	39	39
	For maintenance	12	17	31	31
	Electric power out	56	37	37	35
	Over-current				
	Outlying value		6	117	
	Calibration error			70	70
	Maintenance error		28	44	44
	Poor indication				
	Temperature rise by air-conditioning				
	Water condensation of manifold				
	Out of order of air-conditioning				
	Mechanical trouble by water				
	Mechanical trouble	181	108	1772	1760
	Total	282	205	2110	1979
MS-4	For calibration	56	14	68	68
	For maintenance	9	6	28	28
	Electric power out	81	62	76	76
	Over-current				
	Outlying value		1		
	Calibration error		1	303	303
	Maintenance error				
	Poor indication	9			
	Temperature rise by air-conditioning			10	10
	Water condensation of manifold		109		
	Out of order of air-conditioning	67	67	718	718
	Mechanical trouble by water				
	Mechanical trouble		20	487	484
	Total	222	280	1690	1687
MS-5	For calibration	32	12	60	60
	For maintenance	6	7	10	10
	Electric power out	199	185	192	192
	Over-current	28	28	28	28
	Outlying value	399	3		
	Calibration error	94		121	121
	Maintenance error			577	577
	Poor indication			6	6
	Temperature rise by air-conditioning				
	Water condensation of manifold		6		
	Out of order of air-conditioning	143	149	149	149
	Mechanical trouble by water	495	70		
	Mechanical trouble	137	2		1
	Total	1559	462	1143	1144
	For calibration				
	For maintenance				
	Electric power out				
	Over-current				
	Outlying value				
	Calibration error				
	Maintenance error				
	Poor indication				
	Temperature rise by air-conditioning				
	Water condensation of manifold				
	Out of order of air-conditioning				
	Mechanical trouble by water				
	Mechanical trouble				
	Total				

The hourly values of SO_2 concentration at each station are listed in the Data File chapter as shown by an example of Table 4-10. A summary of SO_2 measurement is shown in Table 4-9 which shows measurements of all stations satisfying the require ment set by Standards (daily average; 0.3 mg/m^3=0.117 ppm, geometrical yearly mean; 0.10 mg/m^3=0.039 ppm). The detail discussion must resort to the separate part.

Table 4-9 A summary of SO_2 concentration measurements

Station		MS1	MS2	MS3	MS4	MS5
Effective measuring time	(days)*	362	354	352	360	296
Yearly average	(ppb)	7	12	24	5	3
Geometrical yearly mean	(ppb)	4	8	16	3	2
Peak hourly value	(ppb)	109	112	199	79	48
Peak daily average	(ppb)	23	34	71	20	21
Daily average (98%) value	(ppb)	19	30	60	14	8

(*Effective measuring day means one in which hourly value is measured over 20 hours per day.)

Table 4-10 SO_2 concentration measurement data (an example)

********** MONTHLY REPORT ********** PAGE - 11

1988YEAR 2 MONTH ITEM (101) SO2 ST. (1) (MS1) ONEB STATION (PPB)

HOUR / DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	MIN	MAX	AVE	HOUR	TOTAL
1	4	3	3	3	3	4	3	3	3	3	5	1	2	2	2	2	2	7	8	9	8	4	3	4	1	9	4	24	91
2	3	3	3	3	3	3	3	3	3	3	3	3	3	2	2	3	3	6	7	7	8	6	4	3	2	8	4	24	90
3	3	3	3	3	4	3	3	3	2	4	5	4	3	1	2	2	4	8	8	8	9	9	8	9	1	9	5	24	111
4	9	9	5	5	7	7	7	8	9	7	5	5	6	6	8	9	9	7	9	7	11	10	13	7	5	13	8	24	185
5	6	6	6	8	11	6	15	21	10	8****		11	8	10	8	10	9	7	8	10	10	7	10	7	6	21	9	23	212
6	13	12	14	9	8	6	5	6	6	7	13	22	10	9	11	11	10	11	10	12	7	9	8	8	5	22	10	24	237
7	10	12	16	13	9	8	6	5	5	6	14	17	15	12	10	10	14	17	14	13	10	9	9	5	5	17	11	24	259
8	4	4	5	5	6	4	5	6	8	6	7	7	7	7	7	9	10	6	9	11	10	11	9	13	4	13	7	24	176
9	8	8	7	7	7	6	8	10	11	7	7	7	6	7	7	8	7	7	7	9	10	7	9	10	6	11	8	24	187
10	10	11	10	9	18****		6	6	14	8	8	5	5	6	7	7	6	8	13	10	11	11	7	6	5	18	9	23	202
11	5	6	5	6	7	6	5	6	5	6	6	7	9	8	9	11	9	16	14	13	25	13	5	7	5	25	9	24	209
12	22	15	27	9	21	13	15	18	12	11	9	4****		5	21	27	26	29	30	28	24	10	13	7	4	30	17	23	396
13	14	11	8	15	14	15	15	15	8	9	7	7	6	5	7	6	5	9	8	7	11	9	9	11	5	15	10	24	231
14	13	6	6	8	6	8	6	7	12	7	4	4	3	4	4	6	6	8	5	5	6	9	5	4	3	13	6	24	152
15	3	5	4	5	8	6	7	10	8	7	6	3	3	4	5	7	6	5	4	6	18	13	8	7	3	18	7	24	158
16	5	6	4	5	5	4	5	4	4	5	5	5	4	4	5	5	6	5	7	7	8	9	11	14	4	14	6	24	142
17	8	8	5	5	6	9	5	7	7	7	9	11	7	9****		8	4	3	2	3	5	7	10	14	2	14	7	23	159
18	12	10	9	7	11	22	15	12	12	10	8	5	4	3	3	3	2	3	5	8	10	10	7	5	2	22	8	24	196
19	3	4	4	5	5	7	5	6	5	3	3****		1	2	2	2	2	2	4	7	8	5	2	2	1	8	4	23	89
20	2	4	3	3	4	4	4	8	5	4	3	5	8	6	7	8	7	5	4	7	8	9	7	4	2	9	5	24	129
21	2	4	4	3	3	3	5	7	4	4	3	3	3	4	4	4	4	3	4	19	20	15	11	9	2	20	6	24	145
22	7	6	5	6	6	6	7	8	9	6	4	5	3	3	4	4	3	4	7	24	31	42	28	19	3	42	10	24	247
23	11	7	4	6	7	7	14	19	24	11	6	4	5	5	3	3	4	10	34	34	73	47	41	21	3	73	17	24	400
24	11	7	7	7	6	7	7	8	7	5	6****		4	6	7	7	8	9	9	10	8	5	5	5	4	11	7	23	161
25	5	5	4	10	8	7	5	9	12	7	6	6	5	6	7	6	6	5	4	5	6	4	6	8	4	12	6	24	152
26	9	10	10	9	6	5	5	8	10	6	10	6****		9	7	6	7	5	4	5	5	10	9	12	4	12	8	23	173
27	8	5	9	8	6	5	3	6	11	9	7	6	5	5	5	5	4	4	5	4	7	8	8	7	3	11	6	24	150
28	4	6	8	7	5	6	5	4	4	4	4	4	4	4	4	4	4	3	4	6	6	4	4	3	3	8	5	24	111
29	3	4	6	6	5	6	6	8	7	5	5	5	6	4	5	5	6	5	6	8	6	5	6	7	3	8	6	24	135
MIN	2	3	3	3	3	3	3	3	2	3	3	1	1	1	2	2	2	2	2	3	5	4	2	2	1				
MAX	22	15	27	15	21	22	15	21	24	11	14	22	15	12	21	27	26	29	34	34	73	47	41	21		73			
AVE	7	7	7	7	7	7	7	8	8	6	6	6	5	5	6	7	7	7	9	10	13	11	9	8			8		
HOUR	29	29	29	29	29	28	29	29	29	29	28	27	27	29	28	29	29	29	29	29	29	29	29	29				689	
TOTAL	217	200	204	195	215	193	200	241	237	185	178	172	145	158	173	198	193	217	253	302	379	317	275	238					5285

4.1.2 Measurement of NO_2 atmospheric concentration

In order to investigate the status of pollution by NO_2 concentration at Samut Prakarn Industrial District, five monitoring stations were placed within the territory where the hourly averages of both NO and NO_2 were monitored for one year period by using instruments of automatic and continuously driven type. The instruments were subject to weekly calibration and to the scheduled maintenance once every three months.

(1) Measuring instruments of atmospheric NO_2 concentration

The proposed methods for measurement of atmospheric nitrogen oxides (NO and NO_2) can be mainly grouped into two types, Absorption spectrophotometric method which uses Salzman reagent (wet method) and Chemiluminescence method (dry method). The former is widely in use in countries like Japan, West Germany, South Africa and Italy, whereas the latter is employed by such countries as France, Netherlands, Taiwan, Korea, Singapore, Australia, Canada, United States and others.

(2) The NO_x analyzer used in this project

The type of analyzer used in this survey is one of Chemiluminescence type, which detects chemiluminescence as the result of NO and O_3 reactions as shown below or continuously the NO concentration since the luminescence intensity is proportional to the concentration of NO.

$NO + O_3 = NO_2 + O_2$ ....(4-5)

$NO + O_3 = NO_2^* + O_2$ ....(4-6)

$NO_2^* = NO_2 + h\nu$ ....(4-7)

Namely, NO in the air reacts rapidly with O_3 to form NO_2 , the part of which, say, about 10%, takes the excited state, NO_2^*. When this NO_2^* transforms into NO_2 , the ground state, chemiluminescence is emitted with the wavelength between 600 and 2,500 nm (as shown in Figure 4-5). The spectra of ray is then detected by a photomultiplier tube. In other words, NO is measured indirectly in term of chemiluminescence intensity. Accordingly in order to measure the NO_2 concentration, the system needs a converter to change NO_2 into NO. The NO_2 value is thus thought equivalent to difference of NO_x ($NO+NO_2$) and NO. The converter works to convert the NO_2 of sample air stream into NO and makes it possible to measure the total NO of both NO_2 origin and originally existing portion.

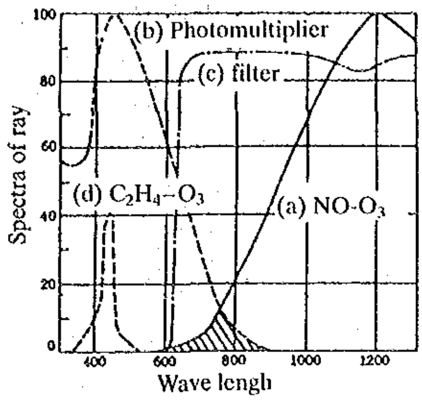


Figure 4-5 The chemiluminescence characteristics of NO-O_3

The instrument applied in this survey is one of chemiluminescence types, GLN-31 manufactured by DKK Corporation, which is featured by a capacity of measuring both NO and NO_2 by letting the sample air every 20 minutes through the converter and of giving the continuous output of both measured data.

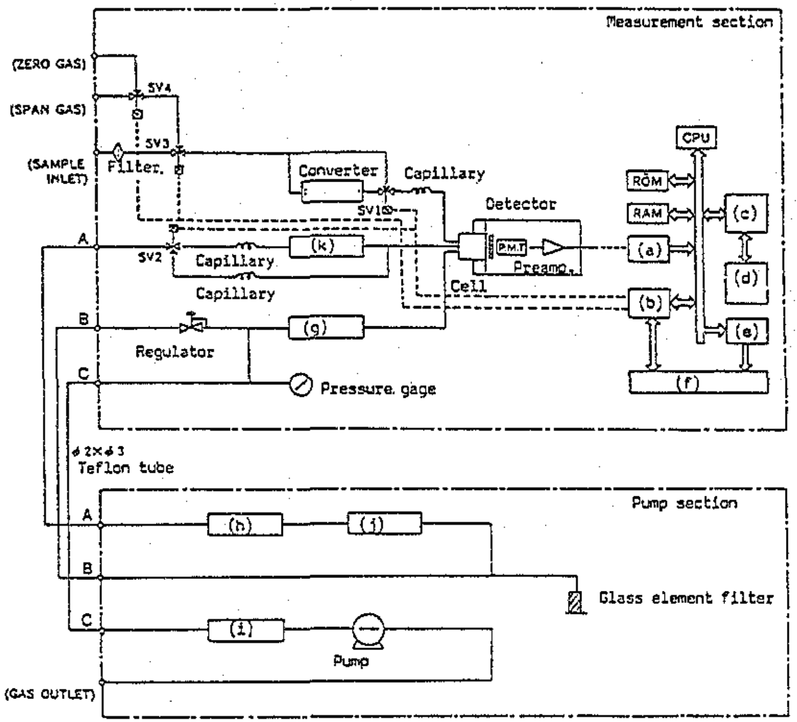
The system also intakes the air intermittently every 4.5 minutes, thereby arrests chemiluminescence and detects the dark current of the photomultiplier as the major source of noise signal, which is stored in the system memory.

The stored information is then utilized to minimize the drift of zero point and to stabilize the measuring conditions. The recording part of the instrument stores both instantaneous and hourly average concentration values of NO and NO_2 and has external I/O terminals and an external output connector, both of which serves to transmit hourly measured values to the data logger.

The instrument is also equipped with an automatic range switching mechanism as such is same case with GFS-31 type SO_2 analyzer. Specifications of the analyzer are shown in Table 4-11, the measurement system diagram in Figure 4-6 and the mechanical structure of analyzer in Figure 4-7.

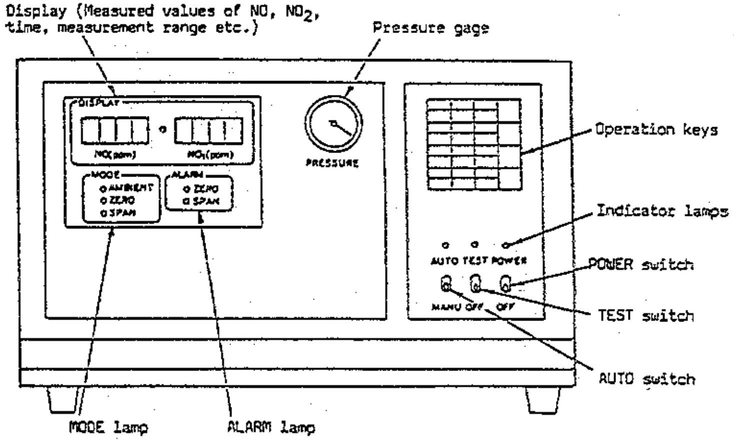
Table 4-11 Major specifications of NO_x analyzer

Name of product:	Atmospheric nitrogen oxides analyzer
Model:	GLN-31
Object components:	Atmospheric NO, NO_2, NO_X
Measurement principle:	Chemiluminescence, continuous measurement
Measurement range:	Instantaneous value 0-0.1, 0-0.2, 0-0.5, 0-1, 0-2, 0-5 ppm. Manually switched 6 ranges. ranges for NO, NO_2, NO_X can be set independently. Hourly average value (Saw-tooth record) 0-0.1, 0-0.2, 0-0.5, 0-1, 0-2, 0-5 ppm Automatically switched 6 ranges.
Indication:	Instantaneous values of NO and NO_2 (Simultaneous indication)
Repeatability:	Within ± 2%FS
Zero drift:	Within ± 2%FS/day
Span drift:	Within ± 2%FS/day
Response time:	Within 3 minutes for 90% response
Ambient temperature:	0-40℃
Power requirements:	100VAC 50 and 60Hz
Power consumption:	250VA
Dimensions:	Measurement section 430(W)x595(D)x270(H) mm Pump section 240(W)x250(D)x280(H) mm
Weight:	Measurement section 32 kg Pump section 7.5 kg
Color painting:	Munsell N4 and N7
Input/output signals:	Transmission output 0-1VDC (Isolated from input), instantaneous and hourly average values of NO, NO_2, NO_X Contact output signals ○ Measurement range signal (Instantaneous and average values of NO, NO_2 and NO_X independently) ○ TEST (under adjustment) signal ○ Blown-fuse signal ○ Under-calibration signal (optional) ○ Automatic-calibration-impracticable signal (optional) Contact input signal ○ External reset signal ○ Observatory (station) stop signal ○ External starting signal of automatic calibration (optional)

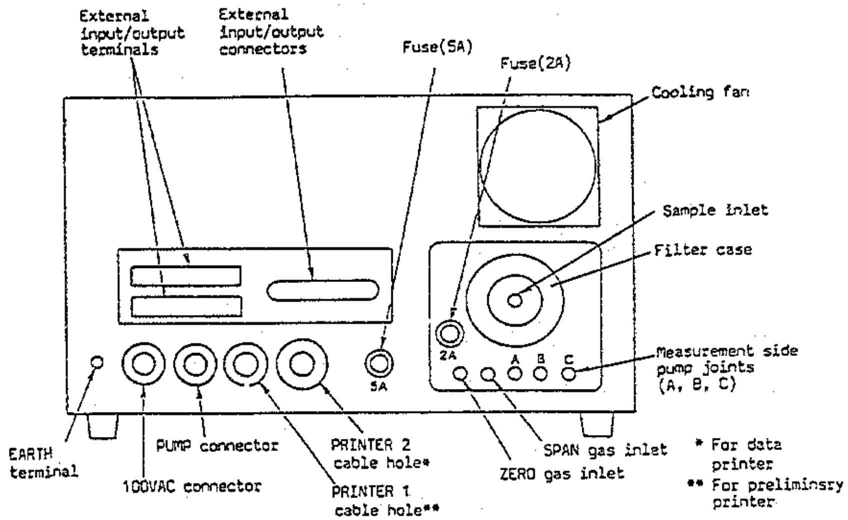


(a) Analog input interface
(b) Digital input interface
(c) Data display interface
(d) Controller
(e) Analog output interface
(f) Input/output terminal board
(g) Ozone decomposer
(h) Activated charcoal 1
(i) Activated charcoal 2
(j) Silica gel
(k) Ozone generator

Figure 4-6 The measurement system diagram of the analyzer



Front panel of measurement section



Rear panel of measurement section

Figure 4-7 (1) The mechanical structure of NO_x analyzer

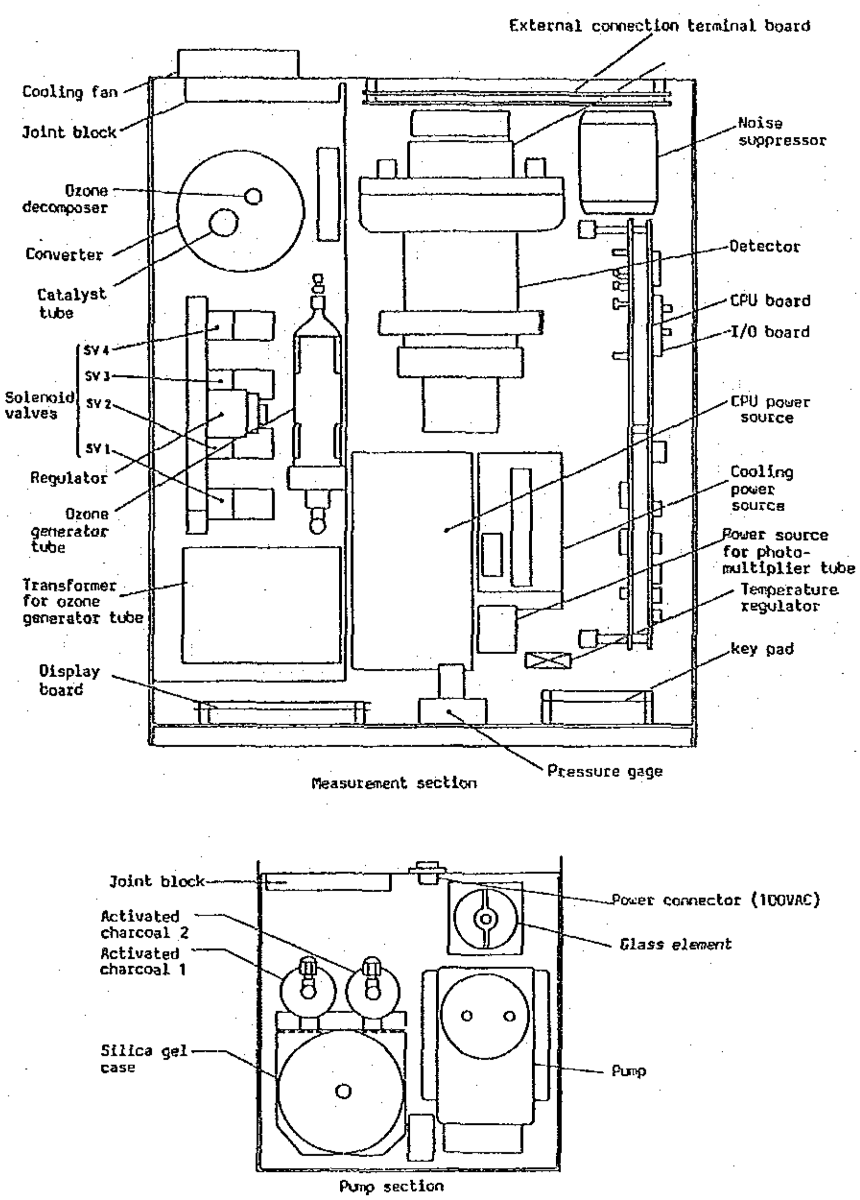


Figure 4-7 (2) The mechanical structure of NO_x analyzer

(3) *Measurements*

The instrument is designed such that operations like calibration, automatic calibration, time adjustment, etc., can be selected by actuating the key panel on its front. The detail description of key operations resorts to the brochures written both in English and Japanese but operation modes available are briefly shown in Table 4-12.

Table 4-12 Operation modes of the NO_x analyzer

Operation item		Keying procedure	Remarks
(1) TIME	Setting	TIME / R.F. / ENT — Press ENT key when the present time agrees with the registered figures.	
	Reading	TIME / ENT (C Released by pressing C key, and display returns to concentration indication.)	
(2) Zero gas introduction		ZERO / ENT (C Released by pressing C key.)	
(3) Span gas introduction		SPAN / ENT (C Released by pressing C key.)	
(4) Span setting value	Setting	SPN.V / R.F. / ENT (After about 1 second, display returns to time indication.)	
	Reading	SPN.V / ENT (C Released by pressing C key.)	
(5) Time of automatic calibration	Setting	CAL.T / R.F. / ENT (After about 1 second, display returns to concentration indication.)	
	Reading	CAL.T / ENT (C Released by pressing C key.)	
(6) Period of automatic calibration	Setting	PER / R.F. / ENT (ENT By pressing ENT key, display returns to concentration indication.)	
	Reading	PER / ENT (C Released by pressing C key.)	
(7) Remaining number of days	Setting	CAL.D / R.F. / ENT (After about 1 second, display returns to concentration indication.)	Perform setting after Auto-Calib-Period setting procedure.
	Reading	CAL.D / ENT (C Released by pressing C key.)	
(8) Manual starting of automatic calibration		S/A / ENT	AUTO switch must be in AUTO position.
(9) Measurement range setting		Instantaneous value NO: RANGE / NO / CONC / R.F. / ENT NO_2: RANGE / NO_2 / CONC / R.F. / ENT NO_x: RANGE / NO_x / CONC / R.F. / ENT Average value NO: RANGE / NO / AVG / R.F. / ENT NO_2: RANGE / NO_2 / AVG / R.F. / ENT NO_x: RANGE / NO_x / AVG / R.F. / ENT	Registered figures are 0.1, 0.2, 0.5, 1.0, 2.0, 5.0 Instantaneous value is switched by hand. Average setting range is the range at starting of each share hour. After then, the range is automatically switched.
(10) Transmission test		R.F. 00-10 / R.F. 1-6 / ENT (C Released by pressing C key.) Test transmission output values and registered figures (see below) Measurement items and registered figures of test transmission output values (see below)	TEST switch in TEST position (ON). Inst.: Instantaneous value
(11) Coefficient	Reading	NO span coefficient. (Symbol on data printer αNO) — keys … ENT NO_x span coefficient. (Symbol on data printer αNO_x) — keys … ENT Span correction coefficient in automatic calibration (Symbol on data printer: β) — keys … ENT Zero correction coefficient in automatic calibration (Symbol on data printer: γ) — keys … ENT Converter efficiency — keys … ENT	
	Setting	NO span coefficient (Symbol on data printer αNO) — keys … ENT; R.F. / ENT NO_x span coefficient (Symbol on data printer αNO_x) — keys … ENT; R.F. / ENT	

Test transmission output values and registered figures

Registered figures	00	05	10
Output value (mV)	0	500	1000
Display	0	500	1000

Measurement items and registered figures of test transmission output values

Registered figures	Measurement item	Registered figures	Measurement item
1	NO Inst.	4	NO Average
2	NO_2 Inst.	5	NO_2 Average
3	NO_x Inst.	6	NO_x Average

(4) Calibration

Prior to calibration, the zero gas generator and the cylindered standard gas (with about 4.5 ppm NO content) supply source are connected to the instrument and then front key panel is actuated to complete the zero point/span corrections. The cylindered standard gas in use is one inspected by Chemicals Inspection & Testing Institute, Japan and has a guarantee period of a half year for its concentration. Therefore the standard gas required the replacement every half a year during the survey period.

(5) Inspection and maintenance

In order to maintain the desirable condition of the NO_x analyzer, it was subject to various inspections and maintenance jobs as listed in Table 4-13 in which weekly and monthly ones were dependent on ONEB and others were performed jointly by ONEB and Japanese staff.

Table 4-13 Inspections and maintenance jobs of NO_x analyzer

	Maintenance object items				Interval					Reference section
	Item		Action	Description	Week	Month	3 months	6 months	Year	
1	Flow path tubing		Check	Fouling, buckling, disconnection, leak		○				
			Replacement	Each tube					□	
			Leak	Leak test			○			
2	Filter case	Element (PF)	Replacement	Replacement by a new one	□					7.2
		Filter case	Cleaning	Joint, case interior			△			
3	Glass element of pump		Cleaning	Glass element			△			7.3
			Replacement	Replacement by a new one					□	
4	Suction pump in pump section		Check	Strange sound, strange vibration		○				
				Normal pressure	○					
			Cleaning	Diaphragm, valve, joint			△			7.4
			Replacement	Replasc diaphragm and valve by new ones					□	
5	Solenoid valve		Check	Strange sound, strange chattering sound		○				7.5
			Replacement	Replacement by a.new one					□	
6	Converter		Replacement	Replace catalyst.					□	7.6
7	Ozone decomposer		Replacement	Replace catalyst.					□	7,7
8	Ozone generating tube		Cleaning						△	
9	Silica gel in pump section		Check	Color change to pink	○					7.8
			Replacement	Replacement by a new or rejuvenated silica gel		□				
10	Activated charcoal 1, 2 of pump section		Replacement	Replacement by a new charcoal			□			7.9
11	Cell		Cleaning	Cell window, cell wall					△	7.10
12	Calibration		Calibration	Zero, span	○					4.5
13	Clock		Check	Check for time shift	○					4.1⑤
14	Capillary		Cleaning	Interior cleaning				△		
			Replacement	Replacement by genuine DKK parts					□	
15	External pipings		Check	Fouling, buckling, disconnection, leak		○				2 .3
			Replacement	Replacement by a new pipe					□	
16	External connections		Check	Looseness, breakdown		○				2 .4

○ : Check for any abnormality. Take specified actions. Adjust to specified values.
△ : Clean specified places.
□ : Replace specified parts for maintaining the performance of the analyzer.

(6) Measurements

The effective measuring hours of both NO and NO_2 contents at each station are shown in Table 4-14. All of them satisfy the minimum requirement hours stipulated for an effective monitoring station in Japan.

Table 4-14 Effective measuring hours of NO and NO_2 at each station

Station	Effective measuring hours		Availability(%)	
	NO	NO_2	NO	NO_2
MS1	8,559	8.560	97.4	97.4
MS2	7,880	7,763	89.7	88.4
MS3	6,674	6,805	76.0	77.5
MS4	7,094	7,097	80.8	80.8
MS5	7,641	7,640	87.0	87.0

Total hours for the period of Jan. 17, 1988 through Jan. 16, 1989 is 8,784 hrs.

As for causes of analyzer troubles, the breakdown is listed in Table 4-8, which indicates a single largest reason for analyzer downtime is the trouble of photomultiplier and the second and third causes are found wrong calibration and power failure respectively. The hourly readings of NO_2 and $NO_x(NO + NO_2)$ at each station are as exemplified in Table 4-16 or more thoroughly in Data File Chapter. The analytical study result is discussed in Part III as well. The summary of measurement results in Table 4-15 shows that the concentrations observed in all stations satisfy the value required by Standards (Hourly value; 0.32 mg/m^3=0.173 ppm).

Table 4-15 A summary of concentration measurement results

Station		MS1	MS2	MS3	MS4	MS5
Effective measuring days	NO_2	354	316	276	289	315
	NO_x	354	316	270	289	315
Yearly average (ppb)	NO_2	16	9	13	15	5
	NO_x	38	18	24	34	9
Geometrical annual mean (ppb)	NO_2	12	6	10	10	3
	NO_x	23	14	18	22	6
Hourly peak value (ppb) (ppb)	NO_2	138	69	81	150	48
	NO_x	497	132	251	343	127
Day average peak value (ppb)	NO_2	49	32	41	69	16
	NO_x	176	56	75	180	36
Day average 98% value (ppb)	NO_2	33	20	30	46	14
	NO_x	112	40	62	105	25

An effective measuring day is one which obtains more than 20 hourly values.

Table 4-16 NO_2 concentration measurement results (example)

********** MONTHLY REPORT ********** PAGE - 13

1988YEAR 2 MONTH ITEM (103) NO2 ST. (1) (MS1) ONEB STATION (PPB)

HOUR / DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	MIN	MAX	AVE	HOUR	TOTAL
1	1	1	1	1	2	4	7	10	7	3	5****		5	9	9	8	11	10	7	9	8	6	5	4	1	11	6	23	133
2	3	2	2	3	3	4	7	11	9	8	5	9	10	4	11	17	22	22	19	12	12	10	10	9	2	22	9	24	224
3	2	2	3	3	2	4	8	9	7	2	2	2	1	2	10	9	4	7	11	10	10	7	9	7	1	11	6	24	133
4	6	5	4	4	4	5	8	12	5	2	2	2	4	3	6	7	11	6	5	4	5	4	4	2	2	12	5	24	120
5	2	3	4	2	1	4	13	21	6	6****		14	10	10	9	12	9	5	6	8	6	7	5	5	1	21	7	23	168
6	5	6	6	7	7	7	11	11	13	11	15	19	9	7	13	12	7	11	11	15	11	9	8	8	5	19	10	24	239
7	10	8	20	19	14	12	12	10	8	7	15	19	14	12	8	9	17	16	14	16	11	16	10	5	5	20	13	24	302
8	5	4	4	4	5	5	10	13	9	5	5	8	5	6	5	9	12	6	5	6	5	5	5	4	4	13	6	24	150
9	4	4	4	4	5	8	9	17	15	4	3	4	4	5	4	5	4	4	5	6	10	11	9	9	3	17	7	24	157
10	6	7	8	6	15************************************										8	4	4	5	10	11	15	18	15	13	4	18	10	15	145
11	18	16	14	12	10	11	11	12	13	10	5	3	4	4	3	4	4	6	10	12	10	8	4	4	3	18	9	24	208
12	7	24	24	10	21	25	29	31	27	18	12********			19	39	44	49	55	49	40	28	17	18	9	7	55	27	22	595
13	22	24	17	21	27	29	28	29	21	12	9	8	8	7	8	7	8	11	16	13	17	16	11	12	7	29	16	24	381
14	10	7	7	7	7	7	18	29	26	7	7	6	8	6	8	9	10	8	8	9	15	15	7	6	6	29	10	24	247
15	5	8	6	5	6	7	11	20	12	5	5	5	9	7	10	12	8	6	7	7	11	16	15	28	5	28	10	24	231
16	28	24	20	18	11	11	15	16	15	19	11	7	5	7	5	5	5	6	8	12	10	8	10	9	5	28	12	24	285
17	8	7	8	6	6	8	9	19	20	17	15	16	9	14****		18	8	10	10	10	17	28	30	28	6	30	14	23	321
18	29	28	24	24	25	24	23	26	24	27	19	10	7	5	5	6	5	7	29	42	39	32	27	20	5	42	21	24	507
19	17	19	18	19	26	27	22	24	16	7	7****		7	6	6	6	6	7	40	58	55	37	15	11	6	58	20	23	456
20	11	9	11	11	16	15	18	30	17	11	23	30	25	27	27	28	20	11	18	50	60	54	32	12	9	60	24	24	566
21	15	18	15	15	13	20	29	28	16	9	7	5	6	6	9	7	6	8	26	70	66	63	54	46	5	70	23	24	557
22	39	29	26	28	33	25	34	40	36	16	9	11	6	6	8	7	8	10	32	69	83	85	79	61	6	85	33	24	780
23	44	24	16	30	28	20	36	36	46	34	14	6	7	7	6	6	9	39	71	75	69	66	52	25	6	75	32	24	766
24	20	11	10	9	8	9	10	14	9	7	5	6	8	15	11	10	13	15	19	14	10	8	7	6	5	20	11	24	254
25	6	7	7	11	7	8	14	18	18	10	8	8	10	10	9	12	10	6	8	7	6	5	6	7	5	18	9	24	218
26	11	11	14	11	13	10	12	14	15	7	17	9****		17	12	9	7	5	5	5	6	6	5	5	5	17	10	23	226
27	3	4	4	4	11	11	9	11	16	9	7	6	4	4	6	5	5	5	6	7	7	6	5	4	3	16	7	24	159
28	4	6	8	5	5	5	8	8	8	5	5	3	6	5	6	5	5	3	5	6	5	5	4	4	3	8	5	24	129
29	2	8	7	4	4	7	13	16	7	3	4	6	9	3	4	5	7	5	10	9	7	7	7	7	2	16	7	24	161
MIN	1	1	1	1	1	4	7	8	5	2	2	2	1	2	3	4	4	3	5	4	5	4	4	2	1				
MAX	44	29	26	30	33	29	36	40	46	34	23	30	25	27	39	44	49	55	71	75	83	85	79	61		85			
AVE	12	11	11	10	12	12	16	19	16	10	9	9	8	8	9	10	10	11	16	21	21	20	16	13			13		
HOUR	29	29	29	29	29	28	28	28	28	28	27	25	26	28	28	29	29	29	29	29	29	29	29	29				680	
TOTAL	343	326	312	303	335	332	434	535	441	281	241	222	200	233	265	297	294	315	470	612	614	575	468	370					8818

4.1.3 Atmospheric concentration measurement of suspended particulate matter

In order to grasp the pollution status quo by the suspended particulate matter, five monitoring stations were installed across the Samut Prakarn Industrial District and hourly SPM average concerations were measured. The calibration and scheduled inspection are practiced once every month and once every three months respectively.

(1) SPM measuring method

There are basicly six groups of method proposed for the measurement of atmospheric particulate matter concentrations as shown in Table 4-17. Among them, types of analyzer that allow the automatic measurement of hourly values are Digital particulate meter, β-ray absorption method, Piezoelectric balance method. Each of these six methods has good and bad points and varies in measured diameter of particulate matter. Accordingly which method to be employed depends largely on various conditions of the country. In Japan, the total suspended particulates (TSP) is defined as dust suspended in the atmospheric air and the portion of such dust in diameter less than 10 μm is called Suspended Particulate Matter (SPM). The implication of this definition is that such SPM can deposit inside the human lung and influence his respiratory organs. Thus the control standards was set for the SPM concentration in the air and simultaneously the Low volume air sampler with a sorting device for 10 μm size particles is employed as standard method. But this method is not suitable for a short term measurement. To cover this weakness of Low volume sampler, Piezoelectric balance meter and β-ray absorption type dust meter are added as standard methods to make hourly measurement possible.

(2) Dust meters applied to this survey

The type of dust meter used in this survey is a β-ray absorption meter suitable for the measurement of hourly SPM concentration. The beta-ray analyzer is an instrument based on the principle that absorption rate of beta-ray increases in propotion to the mass of the substance when its quality remains constant and the ray at a low energy level irradiates the substance. Thus the beta ray irradiation on the particulate matter collected on the filtration paper gives informations about its quantity.

The relationship between intensity of beta-ray transmitted and dust quantity is expressed by the following equation

$$I = I_o \exp(-\mu m \cdot Xm) \quad \text{................................} \quad (4\text{-}8)$$

where;

I : Beta ray intensity transmitted through filter and particulate matter

I_o : Beta ray intensity transmitted only through filter

μm : Mass absorption coefficient (cm^2/g)

Xm : Mass of particulate matter (g/cm^2)

Table 4-17 Classification of measuring method of atmosphere particulate matter concentration

Monitoring method	Monitoring instrument	Principle	Size range	Remarks
Filter contamination method	Smoke sampler (OECD method)	o Suck air through white filter. Usually 24 hours. Contamination of filter is measured by reflection index meter. Value is converted to International smoke unit (ug/mg). Simple mechanism and fitted to continuous monitoring	0 to 20-30 μm	o Widely used in European countries. Method recommended by OECD. Air sucking speed is low and sample is limited to inhalable particles. The results of monitoring is influenced by black color substances, and not indicating real weight. Limited range of chemical analysis is possible even by small quantity of sample
	Tape sampler (ASTM method)	o Same with OECD method. Sample collected on filter automatically forwarding with 2-6 hours interval. Contamination is evaluated by transparancy index and expressed by haze unit (COH) usually, but some cases, by reflection index (RUDS)	0 to 40 μm	o Flow rate is larger than OECD method. Effective sampling of inhalable particles is possible by method employed in USA. Fitted for continuous monitoring.
Filtration sampling method	High volume sampler	o Air is sucked through glass fibre filter usually by turbine blower. Collected sample is weighed under constant temperature and humidity. Most widely used and in West Germany membrane filter and rotary pump are employed.	0.1 to 80-100 μm	o Widely used in USA. Particulate larger than inhalable particle is apt to be collected, and not fitted for monitoring in dirty places. Sampling is usually for 6 days with 24 hours cycle. Obtainable enough sample for chemical analysis.
	Low volume sampler	o Principle is same with high volume sampler, but flow rate is far samller and designed to be fitted for long term air sucking.	0 to 20-30 μm	o Flow rate is smaller than high volume sampler and possible to sample inhalable particles effectively. In Japan, used with cyclon type separator or multi-stage separator to cut the particles larger than 10 microns.
Light scattering method	Digital dust analyzer	o By light scattering, directly measure particulate as aerosol. Individual particles are counted and measure particles size or integrate the scattered light from a certain volume of air.	0.5 to 10 μm	o Used as monitor of SPM in Japan in some extent. But calibration is always necessary and evaluation impossible to compare with direct weight method.
Beta ray absorption method	Beta ray absorption mass monitor	o Particulate matter is collected on filter for a certain time (usually 30 min.) continuously. Beta ray irradiated and a part of energy is absorbed. Weight conc. is determined by Beta ray intensity transmitted.	0 to 20 μm (filter system)	o Instrument cost is usually expensive. In West Germany, used for monitoring. Important instrument to study short time variation of particulate.
Piezo balance method	Piezo balance mass monitor	o Based on piezo oscillator method. The weight of particles accumulated on oscillator proportionally change by vibration number, and weight conc. is determined by this relation.	0.01 to 10 μm (electrostatic system) 0.3 to 20 μm (impactor system)	o This method is high sensitive, but defects in electrostatic collection index and impacts of humidity to sample. Detection of weight without removing substances accumulated on quartz is limited.
Particle separating method	Cascade impactor	o Particulates are classified into several stages by impaction. Weight of each substance is directly weighed.	0.5 to 20 μm	o Conc. in certain range of particle size is evaluated. Used in USA but not widely used.
	Dichotomos sampler	o Known as vertical impactor. Particulate is separated to 2 size range and each particle is collected on filter and weighed.	0 to 30 μm	o Used in USA for monitor of sulfate. Under consideration to be used for monitoring particulate matter in USA.

From the equation (4-8), the mass of particulate matter is calculated as

$$Xm = 1/\mu m \ \ln(I_o/I) \quad \cdots\cdots\cdots\cdots \quad (4\text{-}9)$$

Also the concentration of particulate matter is expressed as

$$C = S/V \cdot Xm \times 10^3 = (S/V) \cdot (1/\mu m) \cdot \ln(I_o/I) \times 10^3 \quad \cdots\cdots\cdots\cdots \quad (4\text{-}10)$$

where;

C: concentration of particulate matter (mg/m^3)

S: collection area (cm^2)

V: *air aspiration volume* (m^3)

The type of dust meter used in this survey is a beta-ray absorption one, DUB-12 type manufactured by DKK Corporation. This dust analyzer aspirates the sample air at a fixed rate of 18 liter/min through a cyclone sieve and traps the airborne SPM by a glass fiber made filter which is then irradiated by the beta-ray to measure the transmitted intensity. The mass concentration (mg/m^3) is calculated through an internal data treatment based on above mentioned principle. The measured hourly average values are simultaneously recorded at each station and are transmitted to a data logger in the central observation center.

The detection part of the instrument is designed as shown in Figure 4-8 such that beta-ray channel and air aspiration channel intersect each other at an acute angle where the filter is placed horizontally. The detection part is thus divided into two parts, above and under the filter level. The beta-ray emitting source (Promethium 147, ^{147}Pm) is installed in the upper part and the semiconductor detector (silicon valence electron detector) in the lower part. The mechanical design permits blank monitoring, dust collection and its detection at a same spot and the detection error due to the misplacement of filter is minimized. The arrangement is also recommendable for monitoring of low concentration of dust in a high sensitivity and makes it possible to measure instantaneous values of varying concentrations.

The procedures of measurement conforms to a programme time chart shown in Figure 4-9 which covers such operations as filter forwarding, blank monitoring, air flow measurement and completes a series of automatic and continuous operations.

Major specifications of beta-ray dust meter and the flow chart of monitoring processes are shown in Table 4-18 and in Figure 4-10 respectively.

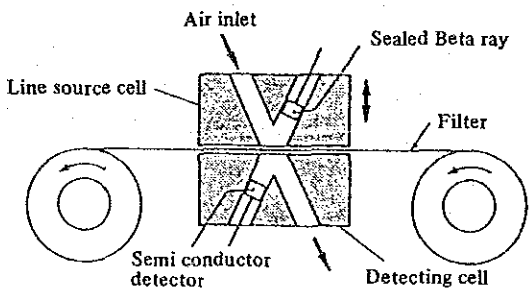


Figure 4-8 The mechanical design of detection part

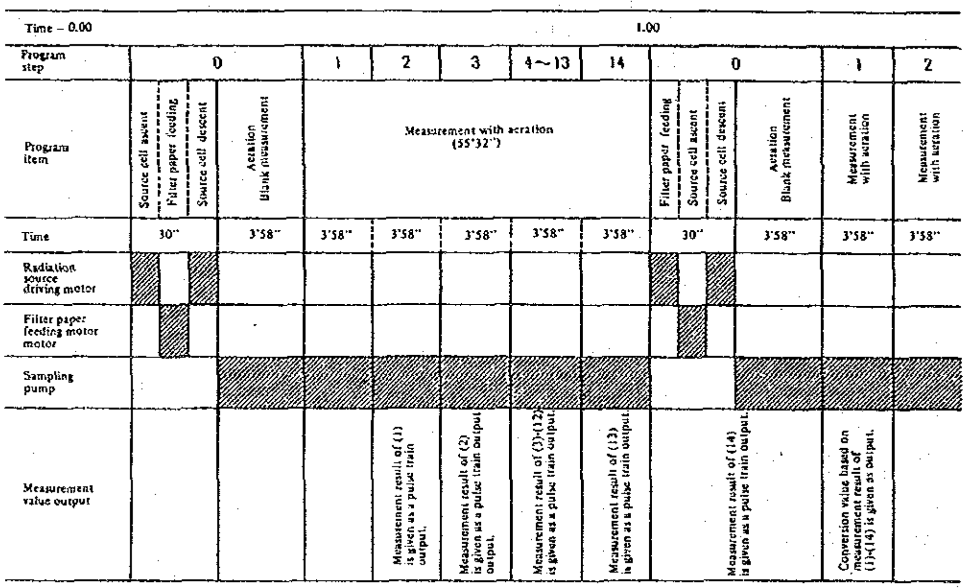


Figure 4-9 The programme time chart

Table 4-18 Specifications of the beta-ray dust meter used in this survey

Name of product:	Atmospheric nitrogen oxides analyzer
Model:	GLN-31
Object components:	Atmospheric NO, NO_2, NO_x
Measurement principle:	Chemiluminescence, continuous measurement
Measurement range:	<u>Instantaneous value</u> 0-0.1, 0-0.2, 0-0.5, 0-1, 0-2, 0-5 ppm. Manually switched 6 ranges. ranges for NO, NO_2, NO_x can be set independently. <u>Hourly average value</u> (Saw-tooth record) 0-0.1, 0-0.2, 0-0.5, 0-1, 0-2, 0-5 ppm Automatically switched 6 ranges.
Indication:	Instantaneous values of NO and NO_2 (Simultaneous indication)
Repeatability:	Within ± 2%FS
Zero drift:	Within ± 2%FS/day
Span drift:	Within ± 2%FS/day
Response time:	Within 3 minutes for 90% response
Ambient temperature:	0-40℃
Power requirements:	100VAC 50 and 60Hz
Power consumption:	250VA
Dimensions:	Measurement section 430(W)x595(D)x270(H) mm Pump section 240(W)x250(D)x280(H) mm
Weight:	Measurement section ≒2 kg Pump section 7.5 kg
Color painting:	Munsell N4 and N7
Input/output signals:	<u>Transmission output</u> 0-1VDC (Isolated from input), instantaneous and hourly average values of NO, NO_2, NO_x <u>Contact output signals</u> ○ Measurement range signal (Instantaneous and average values of NO, NO_2 and NO_x independently) ○ TEST (under adjustment) signal ○ Blown-fuse signal ○ Under-calibration signal (optional) ○ Automatic-calibration-impracticable signal (optional) <u>Contact input signal</u> ○ External reset signal ○ Observatory (station) stop signal ○ External starting signal of automatic calibration (optional)

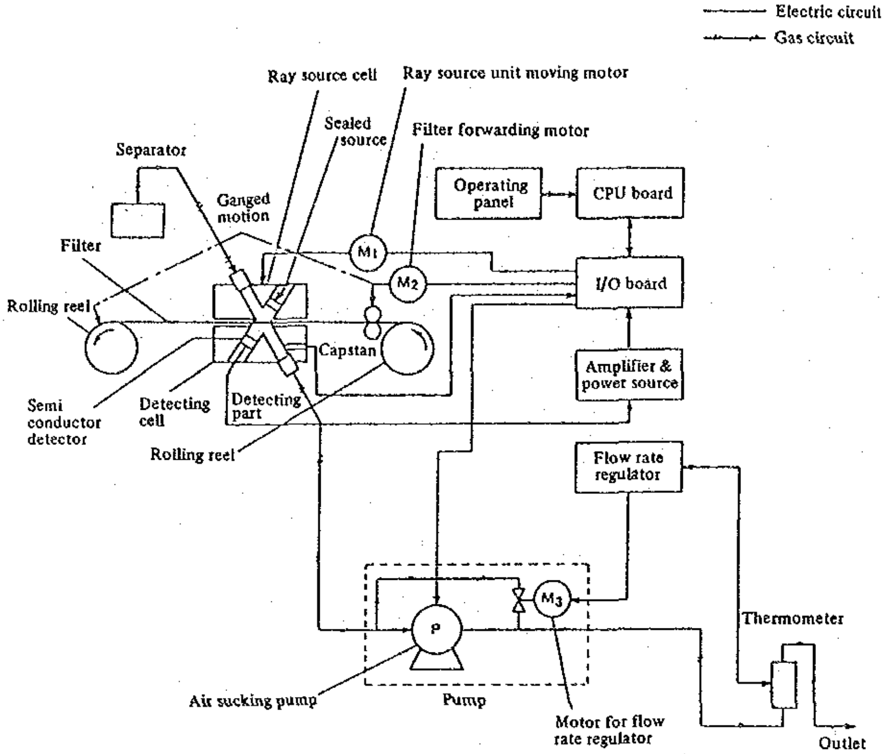


Figure 4-10 The system diagram of beta-ray absorption analyzer

Beta-ray source is Promethium 147 of about 100 microcurie and is designed such that the leakage or permeatation of the radioactive isotope from source container will not cause the environmental pollution problem. It is strictly forbidden to take out the sealed ray source for any reason. In Japan, the qualification, permit and registration are not required for handling such an radioactive substance. Though the half life of Promethium 147 being about 2.6 years, the drift of zero point by time elaspe is small as shown in Figure 4-11 and thus the source can be used longer than 7 years.

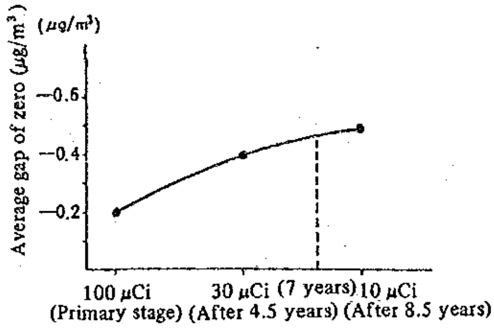


Figure 4-11 The drift of zero point by source intensity

(3) Operations

Operations of the instrument are by the key pannel installed in the front part of the analyzer (as shown in Figure 4-12) and comply with operation modes listed in Table 4-19 which cover automatic monitoring, calibration, time setting, etc. The key operations are described more in detail in brochures Japanese and English.

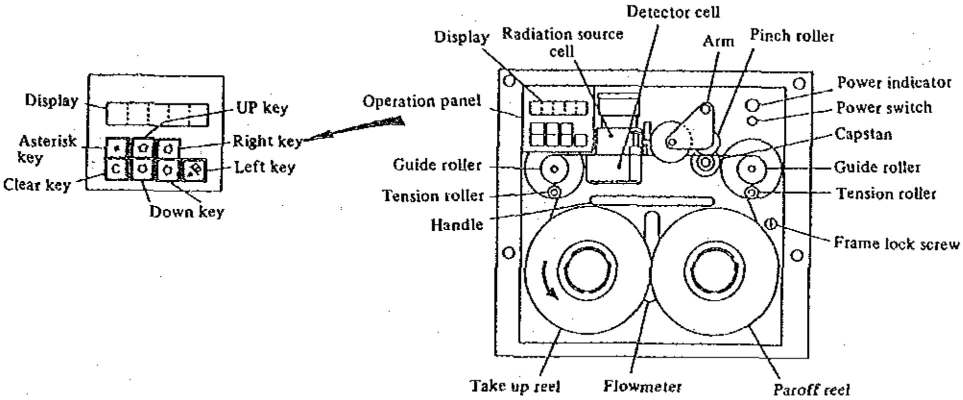


Figure 4-12 Operation board of front part

Table 4-19 Operation modes of the dust meter

Indicater	Mode	Objective
00-00 In case of time mode blinking at a second inverval	Automatic monitor	Normally indicating time (flash 1 sec) alarm signal indicating at abnormal
1	Manual handling	Moving ray source, filter forwarding, ON/OFF of pump, flow rate regulation
2	Equivalent membrane value	Recording and indicating of membrane value
3	Calibration	Blank monitoring, membrane monitor, calibration
4	Span coefficient	Recording and indicating of span coefficient
5	Time	Time correction and indication
6	Month and Day	Correction of month and day
7	Year	Correction of year
8	Station number	Recording of station number
9	Judgement	Confirmation of ROM, recording of corrected number, printing data, confirmation of installed watch
A	Corrected Value A	Recording and indicating of numerical values for zero point adjustment, without changing membrane
b	Corrected Value B	Recording and indicating of numerical values for adjustment of sensibility without changing membrane
c	Transmittance test	Output selecting 10 divided sensibility of 0-1000 pulse/hour

(4) Calibration

The calibration of beta-ray analyzer is done as follows;

(a) Place an equivalent membrane film made of polyamide resin with a premeasured and known blank value on the filter of detecter

(b) Irradiate and get the membrane absorb the beta-ray and read the output of weight concentration corresponding to the thickness of the film.

(c) Confirm the equivalent membrane value or correct, if required, such equivalent value by operating the key pannel.

Figure 4-14 shows results of measuring the equivalent membrane value with respect to several types of material. Reviewing the figures, a linearity is found as seen in Figure 4-14 for materials varying in density.

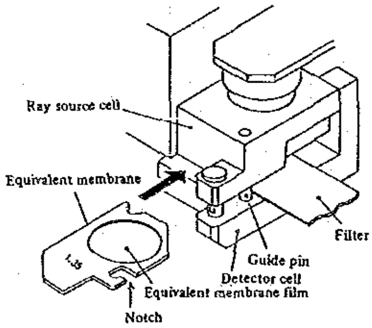


Figure 4-13 Placement of a equivalent membrane

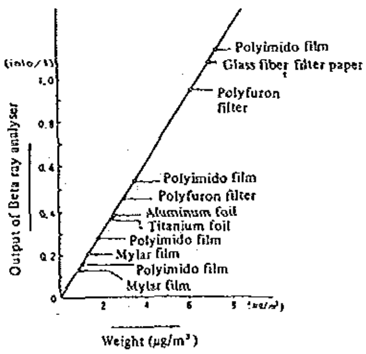


Figure 4-14 The corelation between the output of beta-ray absorption analyzer and the density of equivalent embrane made of various materials.

(5) Inspection and maintenance

The appropriate inspection and maintenance jobs are paramountly important in order to maintain the desirable performance and operation of the analyzer and were practiced as shown in Table 4-20. The monthly replacement of filter, monthly calibration by means of an equivalent membrane and daily inspection were done by ONEB and other inspections jointly by ONEB and Japanese staff.

Table 4-20 Inspection items of beta-ray absorption dust meter

No.	Items to be maintenanced				Interval				
	Item		Action	Description	1 month	3 months	6 months	1 year	
1	Filter paper		Replacement	Replace by a new roll	□				
2	Cyclone sieve section		Cleaning	Dust trap cleaning		△			
			Cleaning	Cyclone sieve cleaning			△		
3	Sampling pump section	Diaphragm	Replacement	Replace diaphragm by a new one.			□		
		Sampling pump	Replacement	Replace or overhaul the pump.				□	
		Braid-hose	Replacement	Replace the hose by a new one.				□	
4	Internal tubing connetions		Cleaning	Internally deposited dust removal		△			
			Replacement	Replace tubes by new ones.			□		
5	Beta ray source cell		Cleaning	Internally deposited dust removal			△		
6	Sampling tube		Cleaning	Inner wall cleaning		△			
			Replacement	Replace by new ones.				□	
7	Calibration		Calibration	With equivalent (calibration) film	○				
8	Flow rate regulator		Adjustment	Balancing adjustment			○		
9	Flowmeter		Cleaning	Cleaning of inner wall and float				△	
10	Flow rate adjust valve		Cleaning	Cleaning of needle and inner wall				△	

(6) Measurement

The effective measuring hours and SPM instrument availability at each station are shown in Table 4-21. The figures show that all of stations satisfy the minimum requirement as effective monitoring station in Japan.

Table 4-21 Effective measuring hours of atmospheric SPM concentration at each station

Station	Effective measurement (hours)	Availability (%)
MS1	8,399	95.6
MS2	8,419	95.8
MS3	8,579	97.7
MS4	8,504	96.8
MS5	8,322	94.7

Total hours for Jan. 17, 1988 through Jan. 16, 1989 is 8,784 hrs.

The breakdown of instrument downtime is shown in Table 4-8. The cause for troubles varies from one station to the other, but the mechanical trouble comes first, then comes power failure next.

The summary of hourly SPM values is shown in Table 4-23 and data recorded by each station are presented in Data File Chapter. A summary of SPM measurement is shown in Table 4-22. The analytical study of them resorts to Part III.

Table 4-22 A summary of SPM concentration measured

Station	MS1	MS2	MS3	MS4	MS5
Effective measuring hours	348	344	355	350	343
Yearly average ($\mu g/m^3$)	60	56	63	68	43
Geometrical yearly average ($\mu g/m^3$)	46	42	50	49	32
Hourly peak value ($\mu g/m^3$)	477	870	702	605	661
Daily peak average ($\mu g/m^3$)	156	169	157	201	119
Daily average 98% value ($\mu g/m^3$)	130	125	132	162	103

An effective measuring day is one when measurements is possible more than 20 hours.

Table 4-23 An example of SPM concentration measured

********** MONTHLY REPORT ********** PAGE - 15

1988YEAR 2 MONTH ITEM (113) SPM ST. (1) (MS1) ONEB STATION (UG/M3)

HOUR DAY	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	MIN	MAX	AVE	HOUR	TOTAL
1	38	41	31	49	43	48	63	91	62	56	21	35	51	40	48	50	52	60	83	119	91	82	62	59	21	119	57	24	1375
2	32	46	40	75	36	64	94	113	118	111	52	57	54	52	52	72	93	108	120	118	132	85	96	117	32	132	81	24	1937
3	52	48	37	84	26	23	35	58	41	30	40	30	33	14	25	40	25	40	58	75	51	51	51	51	14	84	42	24	1018
4	38	30	25	35	35	31	48	61	40	51	86	70	52	50	50	60	71	50	70	59	58	64	62	52	25	86	52	24	1248
5	54	48	64	55	39	51	90	94	53	34	*****	50	40	39	42	48	51	52	48	51	45	47	38	30	30	94	51	23	1163
6	41	45	56	48	37	47	100	128	137	100	116	136	45	29	33	39	39	51	72	193	90	70	60	81	29	193	75	24	1793
7	61	74	80	91	71	100	118	101	110	80	61	110	102	94	60	77	76	94	125	133	96	90	54	50	50	133	88	24	2108
8	48	31	52	51	55	70	75	115	62	41	33	48	40	25	40	49	57	49	54	57	48	51	41	54	25	115	52	24	1246
9	59	40	40	49	54	72	96	140	101	58	60	50	50	25	46	54	56	60	51	53	89	83	80	54	25	140	63	24	1520
10	53	61	54	51	74	60	48	69	110	46	38	39	31	42	32	37	41	42	49	63	72	98	73	72	31	110	57	24	1375
11	92	85	70	64	65	69	83	87	70	56	30	36	35	42	38	30	41	67	80	88	82	74	45	59	30	92	62	24	1488
12	80	129	179	91	133	140	144	101	163	109	115	68	60	78	160	152	153	188	213	168	129	80	75	49	49	213	127	24	3037
13	58	61	50	77	98	120	103	172	141	70	60	61	51	50	54	52	65	72	88	64	90	72	71	61	50	172	78	24	1861
14	68	46	45	50	48	58	80	120	118	50	47	56	46	59	50	52	63	59	63	68	83	72	57	67	45	120	64	24	1525
15	55	51	38	41	62	57	96	144	89	55	52	41	46	59	50	54	70	50	32	37	40	85	77	85	32	144	61	24	1466
16	70	80	90	76	65	82	89	105	90	89	78	54	38	36	31	40	25	33	37	90	75	45	49	48	25	105	63	24	1515
17	24	30	46	41	35	47	61	115	110	86	71	*****	73	47	69	94	31	25	31	38	48	74	89	108	24	115	61	23	1393
18	83	79	129	131	91	93	122	150	142	167	138	81	61	52	45	44	40	38	52	94	118	96	118	89	38	167	94	24	2253
19	41	46	58	42	56	76	69	80	44	40	32	31	51	41	34	40	46	42	72	114	161	130	55	60	31	161	61	24	1461
20	49	60	65	52	47	54	63	90	62	54	62	71	93	81	95	98	106	81	80	110	171	187	116	67	47	187	84	24	2014
21	59	59	61	47	55	54	59	97	75	49	37	43	36	46	50	46	46	57	79	155	190	219	238	221	36	238	87	24	2078
22	217	133	81	104	111	80	98	115	112	60	41	68	51	53	83	70	71	84	115	162	206	294	313	285	41	313	129	24	3087
23	212	130	110	93	86	99	170	190	196	173	76	48	62	57	50	52	46	72	108	303	392	270	232	200	46	392	146	24	3507
24	222	187	159	143	96	108	89	126	73	61	47	*****	38	37	48	43	37	52	49	50	40	20	32	21	20	222	77	23	1778
25	31	41	54	56	59	35	72	140	120	40	50	50	29	37	38	40	40	40	29	47	38	33	51	41	29	140	50	24	1211
26	50	51	51	41	47	36	59	81	61	42	54	35	44	60	42	51	38	43	31	37	45	52	37	36	31	81	47	24	1124
27	39	34	25	30	43	55	55	88	86	43	36	18	35	34	32	31	26	35	41	43	31	30	36	36	18	88	40	24	962
28	22	26	33	39	33	25	41	55	84	40	40	18	25	29	41	41	33	41	43	55	45	41	24	26	18	84	38	24	900
29	21	40	42	37	46	44	70	113	49	22	42	39	34	22	18	30	34	26	31	50	22	23	33	37	18	113	39	24	925
MIN	21	26	25	30	26	23	35	55	40	22	21	18	25	14	18	30	25	25	29	37	22	20	24	21	14				
MAX	222	187	179	143	133	140	170	190	196	173	138	136	102	94	160	152	153	188	213	303	392	294	313	285		392			
AVE	68	63	64	64	60	65	82	112	94	66	58	53	48	46	50	55	54	59	72	93	99	90	82	76			70		
HOUR	29	29	29	29	29	29	29	29	29	29	28	27	29	29	29	29	29	29	29	29	29	29	29	29				693	
TOTAL	1969	1832	1865	1043	1746	1898	2390	3239	2719	1913	1615	1443	1406	1330	1456	1586	1572	1711	2084	2694	2858	2618	2365	2216					48368

4.1.4 Measurement of atmospheric concentration of TSP

In order to analyze the pollution status of Samut Prakarn Industrial District area by TSP (Total Suspended Particulate), Low volume Samplers installed in five stations continued the monitoring for one year survey period. The filter placement, its exchange (once every half month) and instrument inspection were done jointly by Japanese and ONEB staff during 1st through 3rd field trips which lasted 15 days each. The same jobs were carried out by ONEB staff for the remaining ten and a half month period. Each monitoring station had two Low volume samplers, one with a polyfluorocarbon filter to assure elemental and ion analyses and the other with a quartz filter for carbon analysis.

(1) Summary of the investigation

The Low volume samplers were calibrated prior to monitoring service and were brought in each station. Staffs in five groups loaded the filters onto the instruments at 11:00 AM of the measurement starting day and let meters aspirating the atmospheric air at the rate of 10 liters per minute. After the instruments started measurement, staff visited each station twice a day in the morning and in the afternoon and completed recording of data as shown in Table 4-24 as well as flow rate adjustment.

As for weighing of the filters loaded with TSP trapped, they were sent back to Ishikawajima Inspection & Instrumentation Co., Ltd. in Japan and were kept in a constant temp.-moisture bath (thermo-hygrostat) prior to measurement by a chemical balance. The data sheet used is as shown in Table 4-25. The atmospheric concentration of TSP was calculated by knowing both the aspirated air volume and weight of dust trapped by the filter in compliance with the method to be discussed in the succeeding chapter.

Table 4-24 Data recording chart of Low volume sampler

Monitoring Station		Instrument No.		Filter No.		Type of	Polyfront / Quartz	Person in charge	
Monitoring Period	From 198 . . . Morning, Afternoon hour min To 198 . . . Morning, Afternoon hour min			Total Sampling hour hour min (min)		Average Flow Rate Total Absorved Volume		(ℓ/min) (m^3)	a) - before adjustment b) - after adjustment Flow Rate = ℓ/min

Date Month Day	Hour Min	Flow Meter Scale	Pressure (mmAq)	Counter Value		Date Month Day	Hour Min	Flow Meter Scale	Pressure (mmAq)	Counter Value		Date Month Day	Hour Min	Flow Meter Scale	Pressure (mmAq)	Counter Value	
Start								a)						a)			
								b)						b)			
		a)						a)						a)			
		b)						b)						b)			
		a)						a)						a)			
		b)						b)						b)			
		a)						a)						a)			
		b)						b)						b)			
		a)						a)						a)			
		b)						b)						b)			
		a)						a)						a)			
		b)						b)						b)			
		a)						a)						a)			
		b)						b)						b)			
		a)						a)						a)			
		b)						b)						b)			
		a)						a)						a)			
		b)						b)						b)			
		a)						a)						a)			
		b)						b)						b)			
		a)						a)				Remarks					
		b)						b)									

Table 4-25 TSP recording chart of Low volume sampler

Monitoring Station			Instrument No.			Without Cyclon / With Cyclon

Filter No.	Sampling Period Month, Day, Hour, Min.	Incubating time before sampling	Incubating time after sampling	Sampling time(min)	Total flow rate (m^3)	Weight before sampling	Weight after sampling	Sampled volume	Particulate concentr. (μg/m^3)	Laboratory Tem. (°C)	Laboratory Hum. (%)	Remarks
	From:											
	To:											
	From:											
	To:											
	From:											
	To:											
	From:											
	To:											
	From:											
	To:											
	From:											
	To:											
	From:											
	To:											
	From:											
	To:											
	From:											
	To:											
	From:											
	To:											

(2) Instrument

1) Low volume sampler

The instrument is designed such that it can aspirate the ambient air at the rate of 3-25 liter per minute and continuously for the period of a half month in order to trap the total suspended particulate on the filter. The instrument used in this survey (manufactured by Shibata Scientific Technology Co., Ltd. type LT-20) has also a provision to keep the filter holder in a shelter that excludes any influence of rain drops and fallout large size dust particles.

The air aspiration volume is determined by a float type flow meter and a dry-type integrating flow meter attached to the instrument.

Though this Low volume sampler is equipped with a sieve to eliminate the suspended particulate of over 10 micron size before their reaching the filter, the sieve part was removed from the sampler because the objective is not measurement of suspended particulate matter less than 10 micron size, but that of total suspended particulate. The sieve is essentially a multiple horizontal plates arranged in parallel with a small gap between them. When the air passes in laminar flow through this horizontal elutriator, large size airborne particles deposit on the plates as they pass through the clearances while fine dust particles go through with air stream. The penetration rate of the elutriator is calculated by the following Equation (4-11)

$$P(\%) = 1 - \frac{LW \varrho g d^2}{18 \eta v} \qquad \text{(4-11)}$$

where L = length of plates (cm)

W = width of plates (cm)

N = number of plates

ϱ = density of aerosol particles (g/cm^3)

g = acceleration of gravity (m/s^2)

d = effective diameter of aerosol particles (cm)

η = viscosity coefficient of air (poise)

v = flow rate (cm^3/s)

Figure 4-15 shows the typical example of penetration characteristics of a horizontal elutriator. Particles of 10 micron or over can be eliminated when the sampler LT-20 is used at the flow rate of 20 liter per minute.

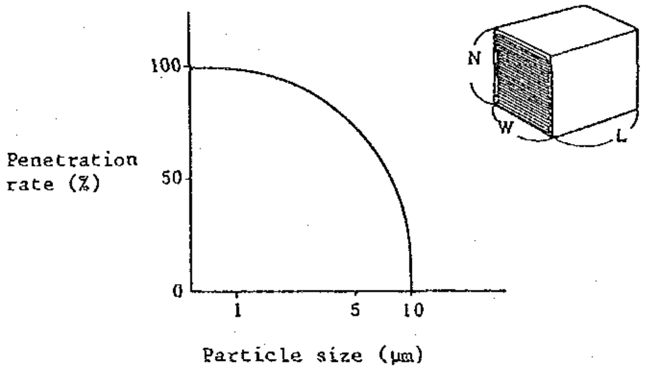


Figure 4-15 The efficiency curve of a multiple plates horizontal elutriator

Specifications of the Low volume sampler used in this study are listed in Table 4-26 and its external appearance in Figure 4-16.

Table 4-26 Specifications of Low volume sampler

Multistage separator (Elutriator)	: Standard 20L/min
Filter holder	: Holder, for 55φmm Clip , for 55φmm 44φmm (Effective)
Flowmeter	: Glass, float type 3 to 32L/min
Integrating gas meter	: Dry type, capacity 0.05 to 59L/min
Vacuum gauge	: 0 to 1000mm H_2O
Suction pump	: AC 100V, 50/60Hz, 35W 1.5/1.1 (A) Flow rate 1 to 25L/min
Power cable	: 5mm, 7A, with ground terminal
Fuse	: 5A, 6.6 x 30
Dimensions	: 600(W) x 480(D) x 1570(H) mm
Accessories	: Glass fiber filter, φ55 100pcs Milipore AP-200 Fuse (5A) 1 pc Driver 1 pc Soft cover 1 pc

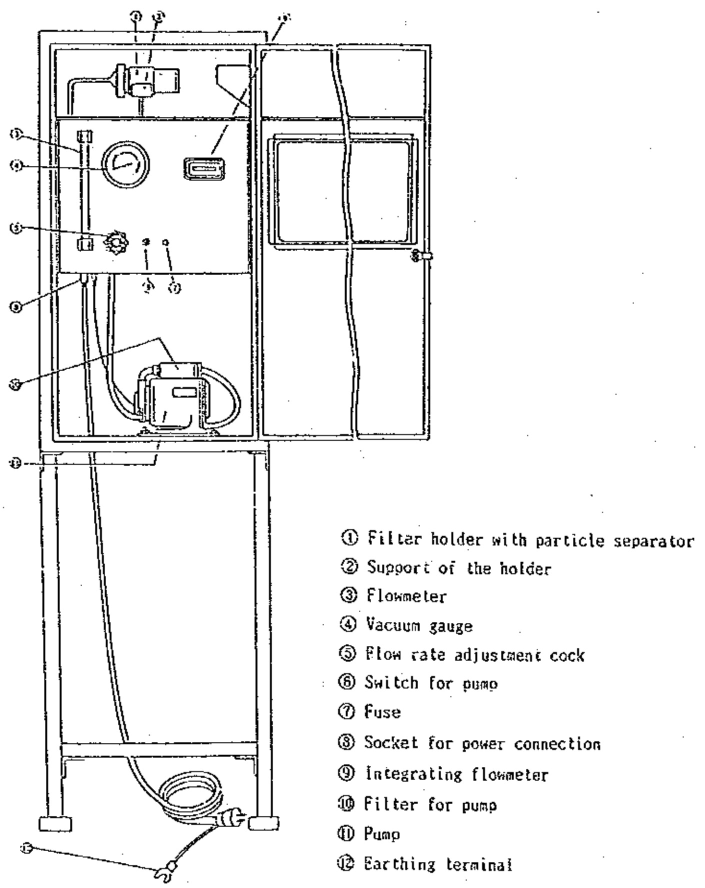


Figure 4-16 The Low volume sampler

The operation procedures of the sampler are as follows:

* The filter is weighed prior to mounting, then placed between the filter holder and adapter and is fixed as illustrated by Figure 4-17.
* Prior to the start of monitoring, time and reading of the integrated flow meter are exactly recorded.
* At three minutes after the power is on, the flow meter is adjusted at a preset point.
* At the end of monitoring, readings of the integrated flow meter, rotameter and pressure gauge are recorded before the power being switched off.

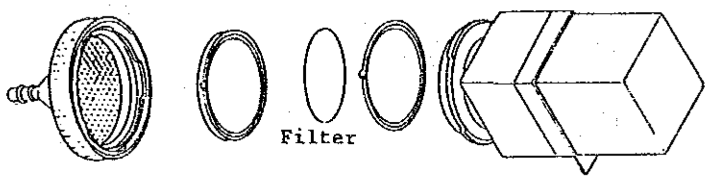


Figure 4-17 Placement of the filter

2) Wet-type gas meter

A wet-type gas meter was employed for calibration of the flow rate of the rotameter installed in Andersen sampler and Low volume sampler and also the integrated flow meter installed in the latter. The type of meter employed is one manufactured by SHINAGAWA KEIKI Co., Ltd. model W-NK-10.

As shown in Figure 4-18, the incoming air through the inlet is led to the front chamber and then to a round shaped drum through suction tube. The interior of the drum is sectioned into 4 chambers water sealed. The air flow is admitted to and goes out from each of these chambers and gives the rotational thrust to the drum (shown by an arrow sign). The air exhaust volume per rotation is constant and thus the integrated flow rate can be calculated by knowing the number of rotations. Specifications of this gas meter and its external appearance are respectively shown in Table 4-27 and Figure 4-19.

In order to calibrate the performance of rotameter and integrated flow meter, the wet-type gas meter, pressure gauge, integrated flow meter, rotameter and the pump were all connected in series as shown in Figure 4-23. Calibrations were done on rotameter readings and count values of the integrated flow meter.

(Please refer the detail discussion to " Calculation of TPM Concentration" by Low volume sampler and Andersen one.)

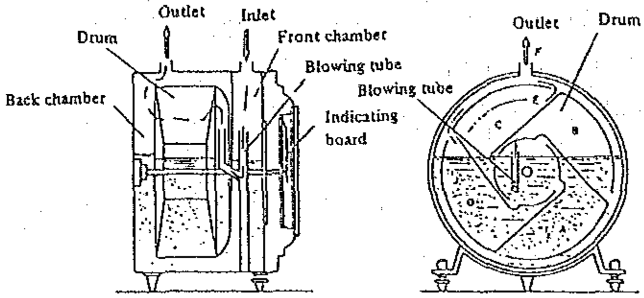


Figure 4-18 The mechanical structure of wet-type gas meter

Table 4-27 Specifications of the wet-type meter

Measuring range:	20 - 6.000 l/h
Drum capacity:	10 liter
Pressure loss:	Under 15 mm H_2O
Indicator board:	1 rotation 10 liter, minimum readint 0.02 1 maximum intergrating volume 9.999 m^3
Maximum pressure:	1,000 mm H_2O
Pressure resistance:	1,500 mm H_2O
Tolerable temperature:	Under 50°C
Weight:	Weight 35 kg, weight at operation 62 kg

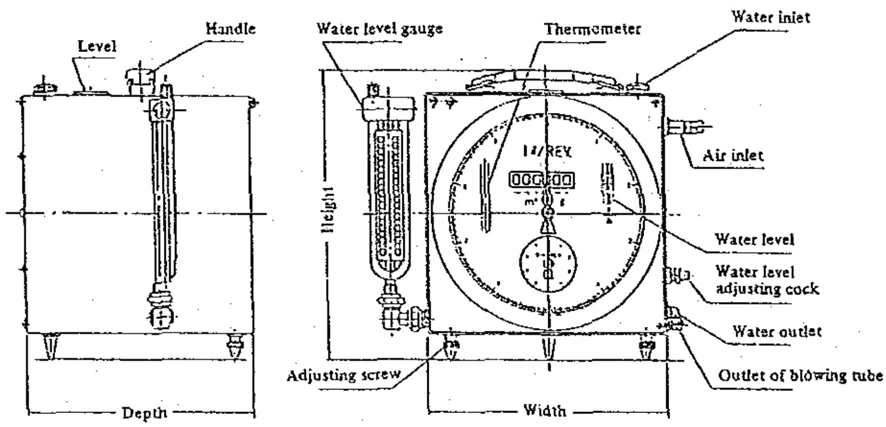


Figure 4-19 The external appearance of wet-type gas meter

The operation procedures of the wet-type gas meter are as follows.

(i) Installation

The wet-type gas meter should be mounted on a flat and stable (vibration-free) table and is positioned at an exact horizontal level.

A level gauge and adjusting screw are to be used.

(ii) Adjustment of the water level

(a) Open a plug of water inlet of blow pipe located in the right side of the meter and pour in the water until the meniscus comes to the level 2 cm above the water level indicator.

(b) Confirmation of water in blow pipe

Open the plug of outlet of blow pipe on the right side of the meter, and check the water. When water is present inside the pipe, the meter will not rotate. Thus drain the water completely and close the plug.

(c) Idle operation

Close the water inlet plug, connect the inlet pipe, and make the meter idly run about 20 to 30 rotations. After idle run, return the inner pressure of meter to the atmospheric one and drain water gradually by means of a level adjusting cock at the right side of meter and keep the water level indicator in the midpoint of meniscus as shown in Figure 4-20.

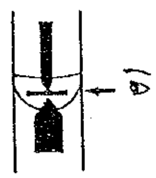


Figure 4-20 Adjustment of the water level

(iii) Leak test

Tightly connect the inlet and outlet tubes to the meter not to cause any leakage and then close the outlet. Apply the pressure from the inlet side and close the inlet. Observe the water level and confirm that no leakage exists.

(iv) Measurement

Connect the inlet and outlet tubes, set the meter in operation the mode and start measurement after about 20 idle rotations of the longer pointer. When a significant difference being observed between water temperature and air temperature, keep idle operations until the former comes to an reasonable agreement with the latter.

(v) Drainage of water

After measurements are completed, the remaining water in the instrument is to be drained completely, by opening the water discharge plug located right and back side of the meter. Confirm the discharge including the inside of drum by tilting the instrument backwardly.

3) Chemical balance

The precision chemical balance is employed for weighing the filters of Low volume samplers and Andersen samplers. Both samplers require a sensitivity of 1/100 mg for weighing the filters and thus selected is Mettler H54AR type semi-micro balance, specifications of which are shown in Table 4-28.

Table 4-28 Specifications of the chemical balance used

Weighing range	up to 170 g
Minimum weighing value	0.01 mg
Standard deviation	plus/minus 0.01 mg

4) Aging box

For storage of filters desiccated before and after sampling of particulate matter, the aging boxes are normally in use. In most cases, $Ca(NO_3)_2$ is placed inside the aging boxes to maintain the filter humidity constant.

However, throughout this survey project, the door of aging boxes were kept open and accordingly the humidity in them were thought same as that of air-conditioned room, 55–65%. (The arrangement is mainly due to the fact that the humidity of aging boxes is often disturbed by door opening and closing when filters were taken in or out.)

5) Filters

Two types of filters were used for Low volume samplers to measure TSP concentration, one made of polyfluorocarbon and the other of quartz fiber.

The former was thought instrumental in improving the elemental and ion analyses, and the latter for analysis of total carbon and non-volatile carbon (inorganic carbon) of the particulate matter.

Specifications of the filters used in this study are listed in Table 4-29.

Table 4-29 Specifications of filters

	Quartz-fiber filter (TOYO-ROSHI QR-100)	Polyfrone filter (TOYO-ROSHI PF040)
Thickness (mm)	0.35	0.95
Weight (g/m^2)	75	560
Percentage of vacant space (Vol. %)	-	73
Pressure loss (mmAq/5 cm/sec)	25	-
Collection efficiency (0.3 μm DOP %)	99	95.0

Sampling characteristics of various filters has long been studied by Industrial Pollution Control Association of Japan (IPCAJ). According to a comparative study made by IPCAJ, four filters made of quartz, glass, membrane and polyfluorocarbon are selected and are subject to experiments at same time/place conditions. The result of such an comparative study is shown in Table 4-30.

Table 4-30 Sampling characteristics of filters

Material	Relative weight
Quartz	0.99
Glass	1.06
Polyfluorocarbon	0.94
Membrane	1.00

The relative weight=each filter weight against the average weight of tested filters.

As shown in the table, the difference of relative weight or particulate trapping characteristics between them is found comparatively small. One can see, however, a slightly higher value in a glass made filter. When such an difference is assumed significant, a possible reason that we can think of might be that the acid gas in the air (mainly SO_2) is adsorbed to the surface of alkaline glass filter and causes an increase in the apparent weight.

The relative weight of polyfluorocarbon filter is found a little smaller than the average, which may suggest a better passing characteristics of the filter. In evaluation of particulate concentration by weighing the filter, the humidity of environment where weighing is performed is a most influential single factor. Accordingly IPCAJ has conducted a study with respect to (a) hygroscopicity of new filters and (b) hygroscopicity of particulate matter. Eight filters made of four different materials, two each of a same material, were weighed in the atmosphere of varying humidity. The effect of humidity on filters were investigated together with the influence coming from type of material. The study result is as shown in Figure 4-21.

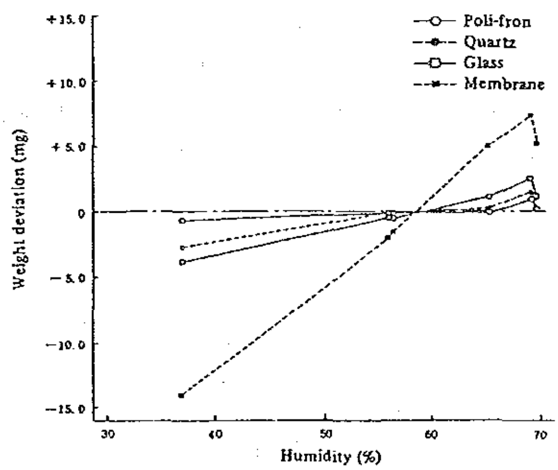


Figure 4-21 Weight change of filters by humidity

As for hygroscopicity of the particulate matter, an investigation was done by using two sets of Low volume samplers, which were continuously operated for two days period while changing the filters (made of quartz and polyfluorocarbon) every 8 hours. The filters loaded with particulate matter were desiccated and weighed in various humidity atmospheres. The study result is as shown in Figure 4-22.

To avoid the hydroscopicity effect of filters, non-used filters were simultaneously weighed and weight increment of them due to varying humidity was subtracted from the measured weight of filters loaded with dust.

From Figure 4-21 one can see the weight increase in all tested filters by increasing humidity, a most significant increase about the membrane filter, glass one coming next and then poly-fluorocarbon filter following. From Figure 4-22, one can see the contribution of humidity change to weight increase being larger in particulate matter than in types of filter.

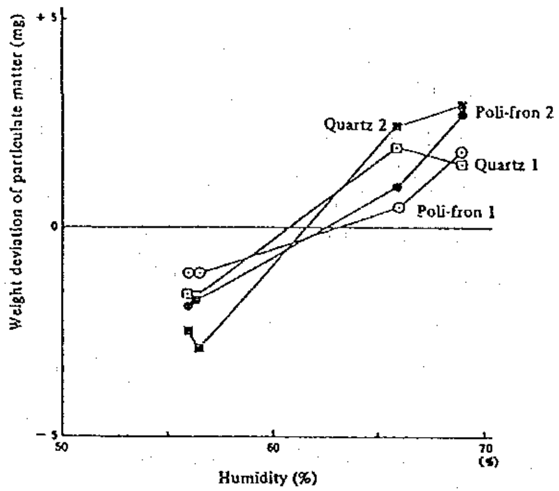


Figure 4-22 Weight change of particulate matter by humidity

(3) Calculation of Total Suspended Particulate

1) Calibration of Low volume samplers

The rotameter and integrated flow meter to be mounted on Low volume samplers were subject to calibration jobs which used a wet-type gas meter as shown in Figure 4-23. The wet-type gas meter, pressure gauge, integrated flow meter, rotameter and a suction pump were all connected in series as illustrated.

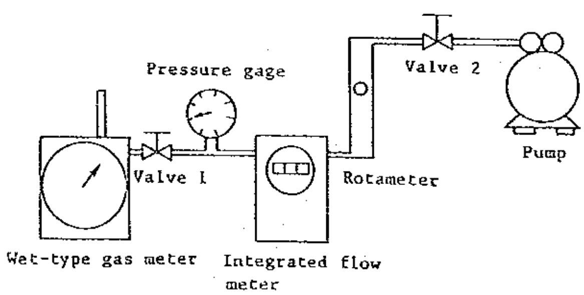


Figure 4-23 Calibration of the rotameter and integrated flow meter for Low volume samplers

(i) The initial readings of the pressure gauge were recorded when new filters (polyfluorocarbon and quartz fiber made) were mounted on the Low volume sampler and the flow rate of rotameter was set at 10 liter per minute.
The readings taken are as shown in Table 4-31.

Table 4-31 Initial pressure values

Type of filters	Initial head loss
Polyfluorocarbon filter	81 mm Aq
Quartz fiber filter	110 mm Aq

(ii) To study the relationship between pressure gauge readings and the rotameter of Low volume sampler, the mounted filters were removed from samplers and then the flow rate of rotameter was again fixed at 10 liter per minute and the water head loss was adjusted to the initial pressure values shown in Table 4-31 by controlling Valve 1.

(iii) While keeping the condition above stated, measured were time and count value of the integrated gas meter required to complete 10 liter air flow through the wet-type gas meter.

(iv) The readings of the pressure gauge were recorded when the flow rate of rotameter were set at 5, 15, 20 and 25 liter/min respectively. Also measured were time requirement and the count value of integrated gas meter to complete the air flow of 5, 10, 15, 20 and 25 liter per minute respectively. Table 4-32 shows an example of measurement and the complete set of data file in Appendix.

(v) The flow rate calculable from the time requirement to complete aspiration of a predetermined amount of air was subject to the temperature correction since the rotameter is designed at 20°C. The equation used for such correction is:

$$Qg_0 = ((273 + T_0)/(273 + \text{Temp.})) \times V \times 60/t \quad \text{.................................} \quad (4\text{-}12)$$

where

Qg_0; the flow rate through the wet-type gas meter at 20°C (liter/min)

Temp.; the wet-type gas meter temperature during calibration (°C)

T_0; the designed temperature of rotameter (20°C)

V; the measured air volume of wet-type gas meter (liter)

t; time required to aspirate the amount of air (s)

(vi) The flow rate Qr at the designed conditions of rotameter is expressed as a function of Qr, reading value of rotameter, as shown by Equation 4-13. An example of such calculation results is also shown in Table 4-32.

$$Qr_0 = Qr\,((273 + T_0)/(273 + \text{Temp.}))^{1/2} \times ((760 - \Delta P)/P_0)^{1/2} \quad \text{..............} \quad (4\text{-}13)$$

where

Qr_0; the flow rate of rotameter at designed conditions (liter/min)

Qr; the reading value of rotameter (liter/min)

P_0; the designed pressure of rotameter (737 mm Hg)

ΔP; the reading value of pressure gauge (mmHg)

T_0; the designed temperature of rotameter (20°C)

Temp.; the temperature during calibration (°C)

(vii) The relation between Qg_0 (the flow rate of wet-type gas meter calculated by Equation 4-12) and Qr_0 (the flow rate of rotameter calculated by Equation 4-13) is expressed by the following equation.

$$Qg_0 = a(Qr_0)+b \quad \text{(4-14)}$$

where a and b are regression coefficients.

Figure 4-24 shows an example of such calculations and the whole set of data file is enclosed in Appendix.

(viii) Qrs_0 (the flow rate when Qg_0 is 10 liter/min) was calculated and then Qr values by Equation 4-15 while keeping the water head loss at 0, 250, 500, 750, and 1000 mmAq respectively. Figure 4-25 shows an example of such calculations and the whole set is enclosed in Appendix.

Reference figures obtained were also posted on the inside face of shelter door of Low volume samplers at each station.

$$Qr = Qrs_0/((273 + T_0)/(273 + Temp.))^{1/2} \times (760 - \Delta P)/P_0)^{1/2} \quad \text{(4-15)}$$

where

Qr; the reading value of rotameter (liter/min)

Qrs_0; the flow rate of rotameter calculated by Equation 4-14 while keeping Qg_0 at 10 liter per minute (liter/min)

P_0; the designed pressure of rotameter (737 mmHg)

ΔP; the reading value of pressure gauge (mmHg)

T_0; the designed temperature of rotameter (20°C)

Temp.; average temperatures expected at survey spots

Jan. to Feb.	27.0°C
Mar. to Apr.	29.8
May to June	29.4
July to Aug.	28.6
Sept. to Oct.	28.1
Nov. to Dec.	26.6

Table 4-32 Calibration result of the rotameter for Low volume samplers

No1070236 MS1-Q

Pressure ΔP <mmAq>	Flow Meter Scale	Counter Value			Total Sampling Volume<L>	Sampling Time <sec>	Wet Gas Meter Temp<°C>	Flow Val.Qg0 <L/min>	Ave. Qg0	Flow Val.Qr0 <L/min>
		Before	After	Total Count						
40	5	257.2	262.6	5.4	5	61.23	24.2	4.8303	4.83	5.03
40	5	264.6	269.6	5.0	5	61.35	24.2	4.8209		
110	10	44.9	55.3	10.4	10	64.04	24.2	9.2367	9.24	10.03
110	10	59.5	70.3	10.8	10	64.00	24.2	9.2425		
247	15	78.8	89.5	10.7	10	42.48	24.2	13.9247	13.89	14.94
247	15	99.0	109.8	10.8	10	42.67	24.2	13.8627		
462	20	132.0	154.0	22.0	20	63.16	24.2	18.7309	18.72	19.70
462	20	160.4	182.3	21.9	20	63.23	24.2	18.7101		
732	25	197.7	220.0	22.3	20	51.19	24.2	23.1108	23.15	24.27
732	25	225.3	247.5	22.2	20	51.02	24.2	23.1878		

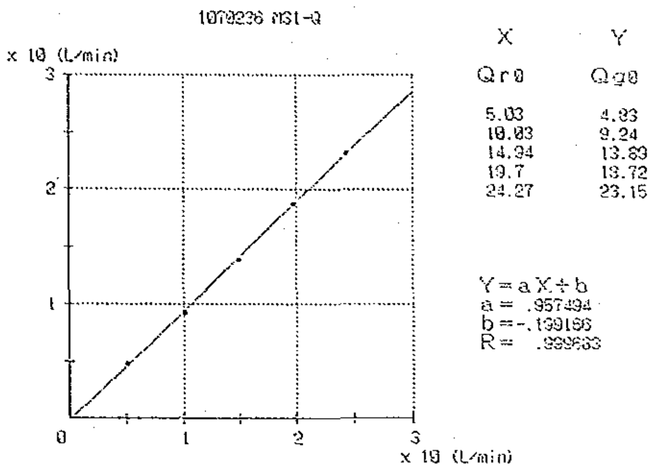


Figure 4-24 The relationship between the flow rate of Wet-type gas meter and that of rotameter

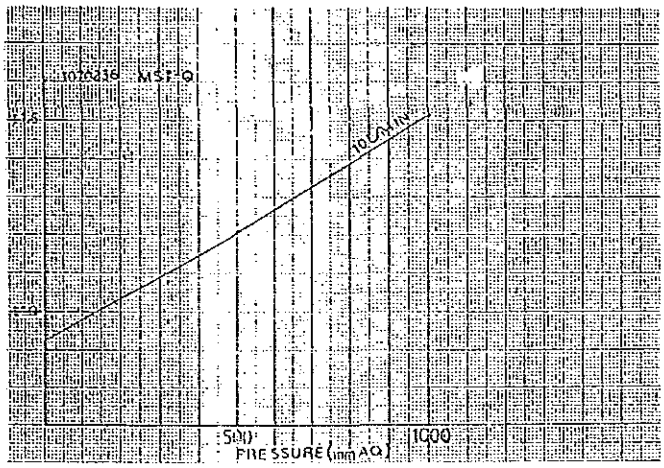


Figure 4-25 The relation between reading value of rotameter and that of pressure gauge while air aspiration volume being kept at 10 liter/min

2) Air aspiration volume of Low volume samplers

(i) Estimation of aspirated air volume from reading value of rotameter and that of pressure gauge

The total air volume aspirated through Low volume samplers was calculated by summing up incremental aspirations (R_i) between ($i-1$) and (i) patrol which were subject to temperature correction.

(a) Firstly, the flow rates of rotameter before and after it was adjusted by patrol members were corrected according to both Equation 4-16 and Equation 4-17 to meet the design conditions of 20°C and 737 mmHg.

$$Qra_{0i-1} = ((760 - \Delta Pa_{i-1})/P_0)^{1/2} \times ((273 + T_0)/(273 + \text{Temp.}))^{1/2} \times Qra_{i-1} \quad \text{(4-16)}$$

$$Qrb_{0i} = ((760 - \Delta Pb_i)/P_0)^{1/2} \times ((273 + T_0)/(273 + Temp.))^{1/2} \times Qrb_i \quad \cdots\cdots (4\text{-}17)$$

where

Qra_{0i-1}; the flow rate after adjustment at (i−1) patrol to meet the designed conditions (liter/min)

Qrb_{0i}; the flow rate before adjustment at (i) patrol to meet the design conditions (liter/min)

Qra_{i-1}; rotameter reading value after adjustment at (i−1) patrol (liter/min)

Qrb_i; rotameter reading value before adjustment at (i) patrol (liter/min)

T_0; the design temperature of rotameter (20°C)

Temp.; average temperature expected during measurement (°C)

P_0; the design pressure of rotameter (737 mmHg)

ΔPa_{i-1}; the reading value of pressure gauge after adjustment at (i−1) patrol (mmHg)

ΔPb_i; the reading value of pressure gauge before adjustment at (i) patrol (mmHg)

(b) Secondly, the flow rate Qr_0 at design condition of rotameter was corrected into the flow rate of wet-type gas meter, Qg_0 at 20°C by Equation 4-18.

$$\left.\begin{aligned} Qg_{0i-1} &= a[Qr_{0i-1}]+b \\ Qg_{0i} &= a[Qr_{0i}]+b \end{aligned}\right\} \quad \cdots\cdots (4\text{-}18)$$

where

Qg_{0i-1}; the corrected flow rate to meet the design conditions after adjustment at (i−1) patrol (liter/min)

Qg_{0i}; the corrected flow rate to meet the design conditions before adjustment at (i) patrol (liter/min)

(c) The air volume aspirated R_i during (i−1) partol and (i) patrol was obtained as a product of lapse time and the mean of flow rate after adjustment at (i−1) patrol and that before adjustment at (i) patrol.

$$R_i = (Qg_{0i-1} + Qg_{0i})/2 \times t \times 1/1000 \quad \cdots\cdots (4\text{-}19)$$

where

R_i; the air volume aspirated during (i−1) and (i) patrol (m^3)

t; lapse time during (i−1) and (i) patrol (min)

(d) The total air volume aspirated to meet the design conditions is calculated by summing up all of incremental air volumes aspirated during each patrol time. The total air volume aspirated at field conditions is thus estimated by Equation 4-20.

$$V_1 = \sum_{i=1}^{n} R_i \times ((273 + Temp.)/(273 + T_0)) \quad \cdots\cdots (4\text{-}20)$$

where

V_1; total air volume aspirated at the temperature of monitoring (m^3)

n; number of patrols (excluding the initial startup and including the last patrol when the monitoring job was terminated.)

T_0; the design temperature of rotameter (20°C)

Temp.; the average temperature expected (°C)

Table 4-33 shows an example of such calculations and the data as a whole is enclosd in Appendix.

The estimation of aspirated air volume by the above-mentioned method is incorrect in case the power failures occur. Thus they were monitored by both recording charts (of automatic and continuous monitors) and the count values of the integrated flow meter. The frequency of power failure observed is listed in Table 4-34.

Table 4-33 An example calculation to estimate the air volume to be aspirated by Low volume sampler

MSI-Q   ROTOR NO.1070236   TEMP(°C) 27.0

DATE	TIME		LAPSE TIME (MIN)	STOP TIME (MIN)	ROTOR METER (L/min)	PRESSURE DIFFERENCE (mmAq)	CORRECTED FLOW RATE (L/min)	CALIBRATED FLOW RATE (L/min)	FLOW VOL (m3)
1 /17	11 : 0		0		11.0	110.0	11.5	10.8	
1 /17	15 :43	B	283	0	10.5	105.0	11.0	10.3	3.0
1 /17	15 :43	F	0		11.0	105.0	11.5	10.8	
1 /18	9 :55	B	1092	0	10.9	110.0	11.4	10.7	11.7
1 /18	9 :55	F	0		11.0	110.0	11.5	10.8	
1 /18	14 :46	B	291	0	10.7	110.0	11.2	10.5	3.1
1 /18	14 :46	F	0		10.9	110.0	11.4	10.7	
1 /19	9 :53	B	1147	0	11.0	110.0	11.5	10.8	12.3
1 /19	9 :53	F	0		10.9	110.0	11.4	10.7	
1 /19	15 :20	B	327	0	10.9	110.0	11.4	10.7	3.5
1 /19	15 :20	F	0		10.9	110.0	11.4	10.7	
1 /20	10 :57	B	1177	0	11.0	118.0	11.5	10.8	12.7
1 /20	10 :57	F	0		10.9	118.0	11.4	10.7	
1 /20	15 :59	B	302	0	10.7	116.0	11.2	10.5	3.2
1 /20	15 :59	F	0		11.0	120.0	11.5	10.8	
1 /21	10 :10	B	1091	0	11.2	120.0	11.7	11.0	11.9
1 /21	10 :10	F	0		11.0	120.0	11.5	10.8	
1 /22	10 : 3	B	1433	0	11.0	120.0	11.5	10.8	15.5
1 /22	10 : 3	F	0		11.0	120.0	11.5	10.8	
1 /23	10 :25	B	1402	0	11.0	125.0	11.5	10.8	15.8
1 /23	10 :25	F	0		11.0	125.0	11.5	10.8	
1 /24	8 :50	B	1345	0	11.0	125.0	11.5	10.8	14.5
1 /24	8 :50	F	0		11.0	125.0	11.5	10.8	
1 /25	10 :42	B	1552	0	11.0	125.0	11.5	10.8	16.7
1 /25	10 :42	F	0		11.0	125.0	11.5	10.8	
1 /26	10 :36	B	1434	0	11.0	137.0	11.5	10.8	15.5
1 /26	10 :36	F	0		11.0	137.0	11.5	10.8	
1 /27	15 :36	B	1740	0	10.8	140.0	11.3	10.6	18.6
1 /27	15 :36	F	0		11.0	140.0	11.5	10.8	
1 /28	14 :12	B	1356	0	11.1	145.0	11.6	10.9	14.7
1 /28	14 :12	F	0		11.1	145.0	11.6	10.9	
1 /29	10 :57	B	1245	0	11.1	145.0	11.6	10.9	13.5
1 /29	10 :57	F	0		11.1	145.0	11.6	10.9	
1 /30	11 : 0	B	1443	0	11.3	155.0	11.8	11.1	15.8
		TOTAL	18720 (min)					TOTAL	206.9 (m3)

Regression coefficients; a = 0.957
b = -0.199

Qg0 = a(Qr0) + b

(ii) A method to estimate the air aspiration volume by using count values of the integrated flow meter

a) The flow rate, Y, per one rotation of the integrated flow meter was calculated by knowing the time SE required for X rotations of the meter by Equation 4-21. An example of such calculations is shown in Table 4-35 and other data file is enclosed in Appendix.

$$Y = SE(s)/X(\text{rotations}) \times Qg_0(\ell/\text{min})/60(S/\text{min}) = SE \cdot Qr/60 \cdot X \quad \ldots (4\text{-}21)$$

where

Y;The flow rate per one rotation of the integrated flow meter (liter/count)

SE; time required for X rotations of the meter (s)

Qg_0; the flow rate of wet-type gas meter (liter/min)

b) A regressional equation shown by Equation (4-22) was developed to show the relationship between readings of rotameter and the flow rate of integrated flow meter with respect to one rotation. Equation (4-22) is a third order equation.

$$Y = g(Qr) \quad \cdots\cdots \quad (4\text{-}22)$$

An example of such calculations is shown in Figure 4-26 and other data file is enclosed in Appendix.

Table 4-34 Power failure time

Date/time	Station	Power failure (minutes)	Troubles
11:50–15:40 17/Jan. 1988	MS3	230	Short circuiting of Andersen sampler
16:40–16:50 20/Jan. 1988	MS2	10	Power failure
15:40–15:50 21/Jan. 1988	MS5	10	Power failure
4:00–7:00 10/Feb. 1988	MS5	180	Power failure
10:20–10:40 1/Mar. 1988	MS2	20	Power failure
21:00–23:00 1/Apr. 1988	MS4	120	Power failure
9:30–10:00 10/Apr. 1988	MS2	30	Power failure
3:20–3:40 13/Apr. 1988	MS5	20	Power failure
3:30–4:50 13/Apr. 1988	MS3	80	Power failure
3:40–9:40 13/Apr. 1988	MS2	360	Power failure
4:20–8:20 13/Apr. 1988	MS1	240	Power failure
1:00–3:00 15/Apr. 1988	MS2	120	Power failure
5:10–6:20 7/July 1988	MS3	70	Power failure
16:50–17:30 8/July 1988	MS3	40	Power failure
10:00–12:00 3/July 1988	MS5	120	Power failure
22:10 8/Aug. – 4:00 9/Aug. 1988	MS5	350	Power failure
3:00–6:00 21/Aug. 1988	MS1	180	Power failure
15:10–15:40 20/Aug. 1988	MS2	30	Power failure
3:15–12:15 7/Sep. 1988	MS2	540	Power failure
8:00–11:00 10/Sep. 1988	MS2	180	Power failure
17:10 7/Sep. – 10:20 9/Sep. 1988	MS5	2490	Power failure
0:00–2:00 17/Sep. 1988	MS3	120	Power failure
1:00–11:45 28/Sep. 1988	MS4	645	Power failure
12:40 28/Sep. – 14:15 29/Sept. 1988	MS4	1535	Power failure
14:10–15:20 15/Oct. 1988	MS2	70	Power failure
12:00–15:30 7/Oct. 1988	MS5	210	Power failure
9:30–16:40 30/Oct. 1988	MS1	430	Power failure
16:10 29/Oct. – 12:10 31/Oct. 1988	MS2	2640	Power failure
4:10–6:10 17/Nov. 1988	MS1	120	Power failure
12:10–12:40 24/Nov. 1988	MS2	30	Power failure
9:20–9:50 29/Nov. 1988	MS2	30	Power failure
17:10–19:30 1/Dec. 1988	MS2	140	Power failure
11:50–20:20 5/Dec. 1988	MS2	510	Power failure
20:00 9/Dec.20: – 14:15 12/Dec. 1988	MS4	3975	Power failure
6:40–7:20 10/Dec. 1988	MS5	40	Power failure
9:40–15:10 25/Dec. 1988	MS1	330	Power failure
18:50–19:50 30/Dec. 1988	MS4	60	Power failure

Table 4-35 An example of calibration results of the integrated flow meter for Low volume sampler

Flow Met. No 1070236 MS1-Q

Flow Meter Scale Qr	Integrated Gas Meter count X	Sampling Time SE <sec>	Wet Gas Met. Flow Val. f<Qr><L/min>	Integrated Meter Flow Y<L/count>	Average Y <L/count>
5	5.4	61.23	4.5883	0.8671	0.90
5	5.0	61.35	4.5883	0.9383	
10	10.4	64.04	9.3758	0.9622	0.94
10	10.8	64.00	9.3758	0.9260	
15	10.7	42.48	14.1632	0.9372	0.93
15	10.8	42.67	14.1632	0.9326	
20	22.0	63.16	18.9507	0.9068	0.91
20	21.9	63.23	18.9507	0.9119	
25	22.3	51.19	23.7382	0.9082	0.91
25	22.2	51.02	23.7382	0.9093	

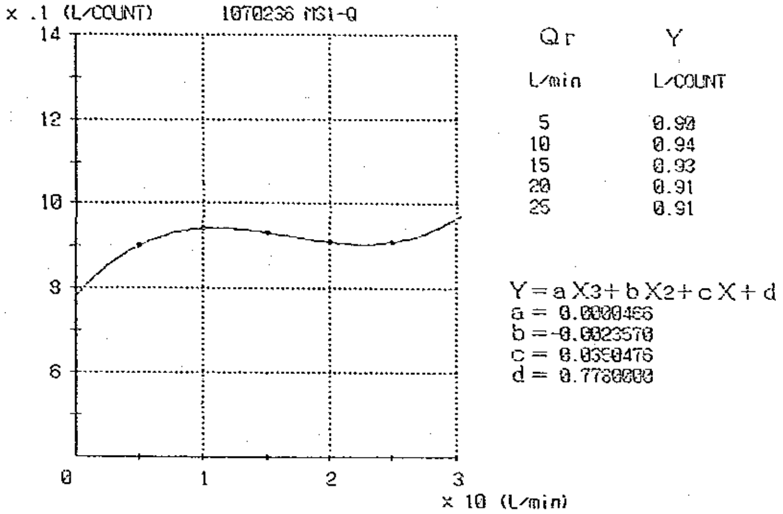


Figure 4-26 The relationship between reading values of rotameter and the flow rate of integrated flow meter per one rotation.

c) The total air volume aspirated by Low volume sampler is obtained by summing up sampling volume R_i for a period of from a patrol to another. The value R_i is calculated by Equation (4-23).

$$R_i = g[(Qra_{i-1} + Qrb_i)/2] \times (IC_i - IC_{i-1}) \times 1/1000 \quad \text{......................} \quad (4\text{-}23)$$

where

R_i; the air volume aspirated during (i−1) and (i) patrol (m^3)

Qra_{i-1}; the reading value of rotameter after adjustment at (i−1) patrol (liter/min)

Qrb_i; the reading value of rotameter before adjustment at (i) patrol (liter/min)

IC_{i-1}; the count number of integrated flow meter after adjustment at (i−1) patrol (count number)

IC_i; the count number of integrated flow meter before adjustment (i) patrol (count number)

d) The total air volume aspirated is obtained by summing up sampling volume R_i during (i−1) and (i) patrol according to Equation (4-24).

$$V_2 = \sum_{i=1}^{n} R_i \quad \cdots\cdots (4\text{-}24)$$

where

V_2; the total air volume aspirated (m^3)

n; the number of patrols (excluding the startup one and including the last patrol to complete the monitoring)

An example of such calculations is shown in Table 4-36 and other data file is enclosed in Appendix.

Table 4-36 An example of aspirated air volume calculations for Low volume sampler

MS1-Q ROTOR NO. 1070236

DATE	TIME		INTEGRATED VALUE (COUNT)	METER TOTAL (COUNT)	ROTOR METER (L/min)	CALIBRATED FLOW RATE (L/count)	FLOW VOL. (m3)
1 /17	11 : 0		430	0	11.0		
1 /17	15 :43	B	3410	2980	10.5	0.940	2.8
1 /17	15 :43	F	3410		11.0		
1 /18	9 :55	B	15156	11746	10.9	0.940	11.0
1 /18	9 :55	F	15156		11.0		
1 /18	14 :46	B	18316	3160	10.7	0.940	3.0
1 /18	14 :46	F	18316		10.9		
1 /19	9 :53	B	30635	12319	11.0	0.940	11.6
1 /19	9 :53	F	30635		10.9		
1 /19	15 :20	B	34201	3566	10.9	0.940	3.4
1 /19	15 :20	F	34201		10.9		
1 /20	10 :57	B	46802	12601	11.0	0.940	11.8
1 /20	10 :57	F	46802		10.9		
1 /20	15 :59	B	50147	3345	10.7	0.940	3.1
1 /20	15 :59	F	50147		11.0		
1 /21	10 :10	B	62032	11885	11.2	0.940	11.2
1 /21	10 :10	F	62032		11.0		
1 /22	10 : 3	B	77441	15409	11.0	0.940	14.5
1 /22	10 : 3	F	77441		11.0		
1 /23	10 :25	B	93164	15723	11.0	0.940	14.8
1 /23	10 :25	F	93164		11.0		
1 /24	8 :50	B	107591	14427	11.0	0.940	13.6
1 /24	8 :50	F	107591		11.0		
1 /25	10 :42	B	124340	16749	11.0	0.940	15.7
1 /25	10 :42	F	124340		11.0		
1 /26	10 :36	B	139696	15356	11.0	0.940	14.4
1 /26	10 :36	F	139696		11.0		
1 /27	15 :36	B	158455	18759	10.8	0.940	17.6
1 /27	15 :36	F	158455		11.0		
1 /28	14 :12	B	173468	15013	11.1	0.940	14.1
1 /28	14 :12	F	173468		11.1		
1 /29	10 :57	B	187118	13650	11.1	0.940	12.8
1 /29	10 :57	F	187118		11.1		
1 /30	11 : 0	B	203047	15929	11.3	0.940	15.0
						TOTAL	190.5

Regression coefficients
a = 4.66E-5
b = -0.002357
c = 0.0350476
d = 0.778
Y = g(Qr0)

3) Calculation of TSP concentration measured by Low volume sampler

TSP concentration was measured by weighing filters before and after samplings. The ambient concentration of TSP is calculated by Equation (4-25).

$$C = (We - Ws)/V \times 10^3 \quad \cdots\cdots (4\text{-}25)$$

where

C; the concentration of TSP ($\mu g/m^3$)

We; the weight of filter after sampling (mg)

Ws; the weight of filter before sampling (mg)