CHAPTER 3 MEASUREMENT OF SO_2 AMBIENT CONCENTRATION

For predicting the future SO_2 concentration, the present concentration of SO_2 emitted from the existing industries is required to be estimated, as well as the impact from the new industries which will be sited under developing plan.

In order to determine the present concentration, measurement by automatic and continuous instruments has been carried out for one year, establishing 7 monitoring stations at industrial, residential, suburban and recreational areas. The installed instruments have been maintained by daily checks and calibration of every 3 months.

II-3-1 Measuring Methods of SO_2 Ambient Concentration

Sulfur oxides in the environmental atmosphere are measured by various methods enumerated in the following Table II-3-1.

Table II-3-1 Measuring methods of ambient sulfur 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

Among the methods enumerated in the above table, the methods from (1) to (4) are standardized by JIS for the automatic and continuous measuring instruments. And in USA, the methods, (2), (3) and (9) are employed by EPA as the standard methods.

Further, in Japan, the method of (1) is employed as the measuring method of ambient standard regulated by Government.

II-3-1-1 Measuring principle of each method and its characteristics

(1) Solution conductmetry

The method is based on the principle that the sample air is introduced into hydrogen peroxide solution acidified by sulfuric acid and measures the sulfuric acid quantity produced by the oxidized atmospheric SO_2 and indicates as the concentration from the solution conductivity change.

The disadvantage of this method is that due to evaporation of water in the solution, the sulfuric acid is concentrated which will cause the measurement errors, and that it is interferenced by the alkali and/or acid gaseous substances during measurement.

(2) Coulometry method

Coulometry method is usually called as constant-potential electrolysis method which is to detect the volume required for electrolysis in the process of oxidation reduction potentiometric.

In the cell filled by electrolytic solution of sulfuric acid solution contained KBr, bromine and bromine ion are kept in the constant balance. When SO_2 contained air is introduced into the solution, the reaction, "$SO_2 + Br_2 + 2H_2O$ --- $H_2SO_4 + 2H^+ + 2Br^{-1}$", is taken place and oxidation reduction potential is generated after Br_2 is deducted into bromine ion. When the potential is compared with the standard potential, the potential difference is corresponding to SO_2 concentration.

Disadvantage of this method is that other sulfuric compounds such as H_2S, CH_3SH and so on are measured simultaneously with SO_2 as these substances are chemically reacted with Br_2.

(3) Flame photometric method

When the sample air is introduced into the flame, the sulfuric compounds generate the strong emission spectrum in the near ultraviolet area in the process of thermal cracking. The emission spectrum of 394 nm is selectively passed through the narrow band pass filter and changed into signal by the photomultiplier tube, and SO_2 concentration is obtained. The method measures other sulfuric compounds except SO_2.

$$SO_2 + 2H_2 \rightarrow S + 2H_2O$$
$$S + S \rightarrow S_2^*$$
$$S_2^* \rightarrow S_2 + hr$$

(4) Ultraviolet spectrophotometry

The method is to detect SO_2 concentration by the intensity of fluorescence generated from SO_2^* in excited state absorbing ultraviolet ray. The reaction equations are as under.

$$SO_2 + hr_1 \rightarrow SO_2^*$$
$$SO_2^* \rightarrow SO_2 + hr_2$$
$$SO_2^* \rightarrow SO + (O)$$
$$SO_2^* + M \rightarrow SO_2 + M$$

The instrument based on this method has the advantage to measure in wide range (up to 500 ppm) without the impact of sample gas flow rate.

(5) Chronoamperometry method (West-Gaeke method)

The absorbing solution of potassium tetrachlorsmercurate absorbs SO_2 in the atmosphere, produces dichlorosulfitomercuratic complex and generates pararosaniline, formaldehyde and pararosaniline methyl sulfonic acid. The absorbance of the solution is measured by spectrophotometry.

This method is based on the manual analysis and so it is generally used for the temporary monitoring in the areas where no continuous and automatic monitoring stations are sited. The disadvantage is apt to be influenced by temperature, particularly in the low temperature area. Also the careful attention should be given to the treatment of solution disposal.

(6) Lead dioxide method

The unglazed ceramic cylinder covered by cotton cloth and painted by PbO_2 is kept in the instrument shelter for a certain period. SO_2 in the atmosphere reacts with PbO_2 and generates sulfate. Measuring sulfate ion from sulfate, the result is indexed by the unit, "mg - SO_3/day/100 cm^2 - PbO_2".

The method is originated back to 1932 when Department of Scientific and Industrial Research of England has developed the method for the purpose of determining SO_2 activity giving impact or damage to the various materials of the buildings. Since then the method has been developed in England, USA, Canada and Japan. At present, it is sometimes used to measure and confirm the tendency of sulfuric compounds concentration in terms of one month.

The disadvantage of the method is that (1) activity of lead dioxide is deviatable, (2) apt to be influenced by wind velocity and temperature, (3) H_2S gives impact, (4) still not confirmed the method to convert into ppm order unit and (5) unsuitable for the measurement in the low concentration areas.

II-3-1-2 Evaluation of measuring methods

A evaluation of measuring methods has been conducted by the Central Research Laboratory of Electric Power Industry (CRLEPI). 10 sets of instruments of 5 principles have been studied as shown in Table II-3-2. The study has been extended to repetition, stability, impact of interference substances and so on.

Table II-3-2 SO_2 analyzers of different principles evaluated

SO_2 analyzer	Measuring principle	Minimum measuring range
A	Coulometry	0 - 200 ppb
B	Ultraviolet spectro-photometry	0 - 200 ppb
C	- ditto -	0 - 100 ppb
D	Chronoamperometry	0 - 200 ppb
E	Flame photometric	0 - 100 ppb
F	- ditto -	0 - 100 ppb
G	- ditto -	0 - 100 ppb
H	Solution conductmetry	0 - 200 ppb
I	- ditto -	0 - 50 ppb
J	- ditto -	0 - 50 ppb

(1) Repetition

Using standard gas generator, zero-gas and span-gas (30 ppb) have been alternately introduced every two hours and 5 times, and the fluctuation coefficient of indicating values have been obtained as shown in Fig. II-3-1.

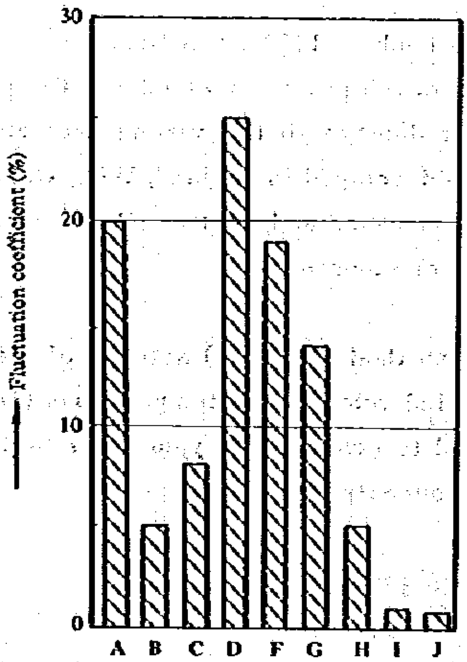

Fig. II-3-1 Comparison of competition tests of SO_2 analyzers

(2) Stability

10 sets of instruments have been calibrated simultaneously and after one week operation of the field site, the stability has been studied as shown in Fig. II-3-2.

B, C, F and G indicate the negative value at low concentration and A shows drifting when zero-gas were introduced at every 16 hours. In case of D, due to the decline of flow rate, the recording was not responded.

I and J which are installed with automatic adjustment system are found satisfactory in stability.

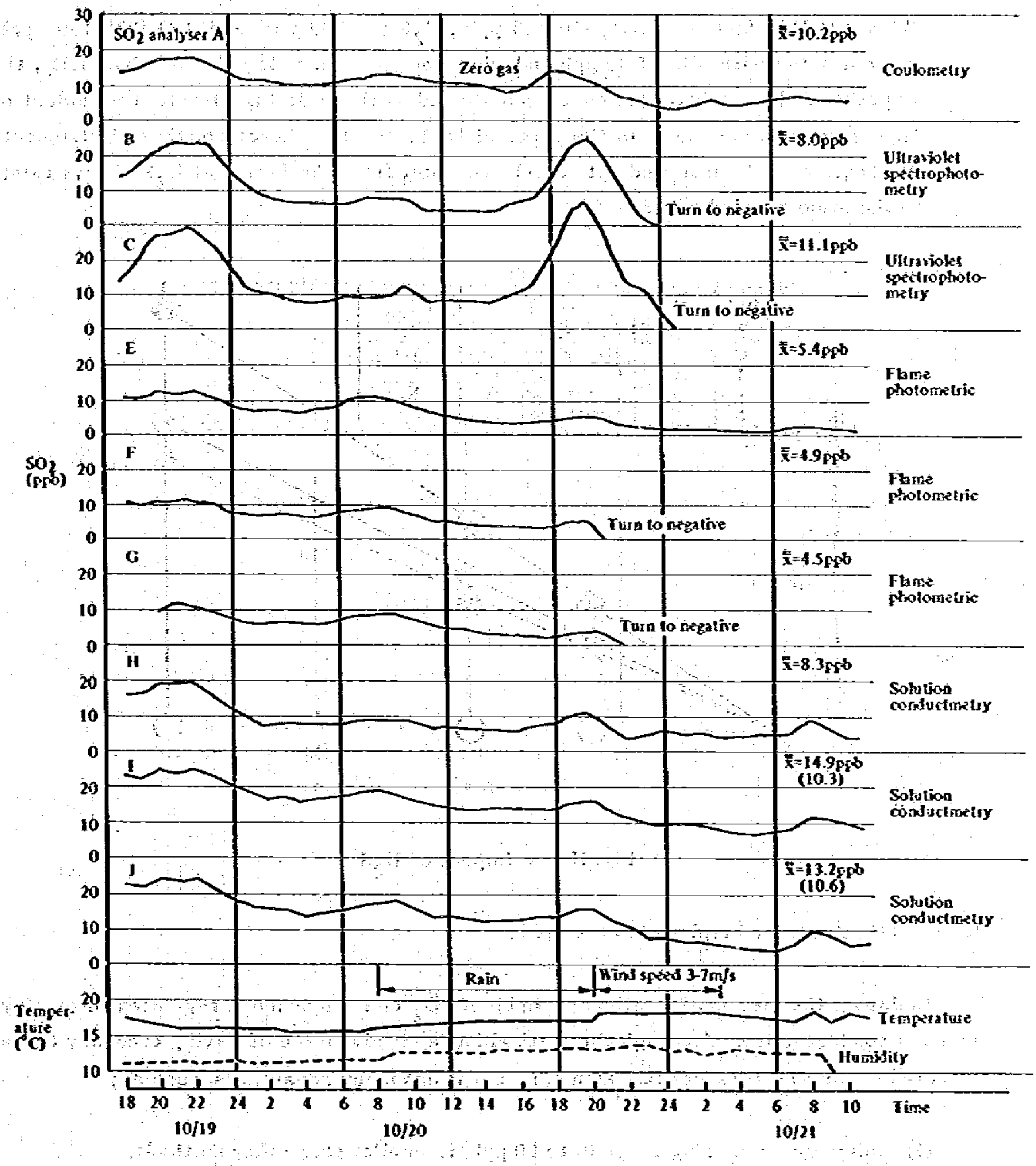

Fig. II-3-2 Results of field measurement by various types of SO_2 analyzer

(3) Impact of interference substances

When NO (120-600 ppb), NO_2 (60-300 ppb), H_2S (60-200 ppb) and CO (375-1500 ppb) are coexisted with SO_2 of 30 ppb and when each substance is existed individually, the impacts of these substances have been studied as shown in Fig. II-3-3. The impact of H_2S is remarkably shown in the cases of D, E, and F. Therefore, these instruments are required to be installed with desulfuring unit from the fact that H_2S always exists in the atmospheric background.

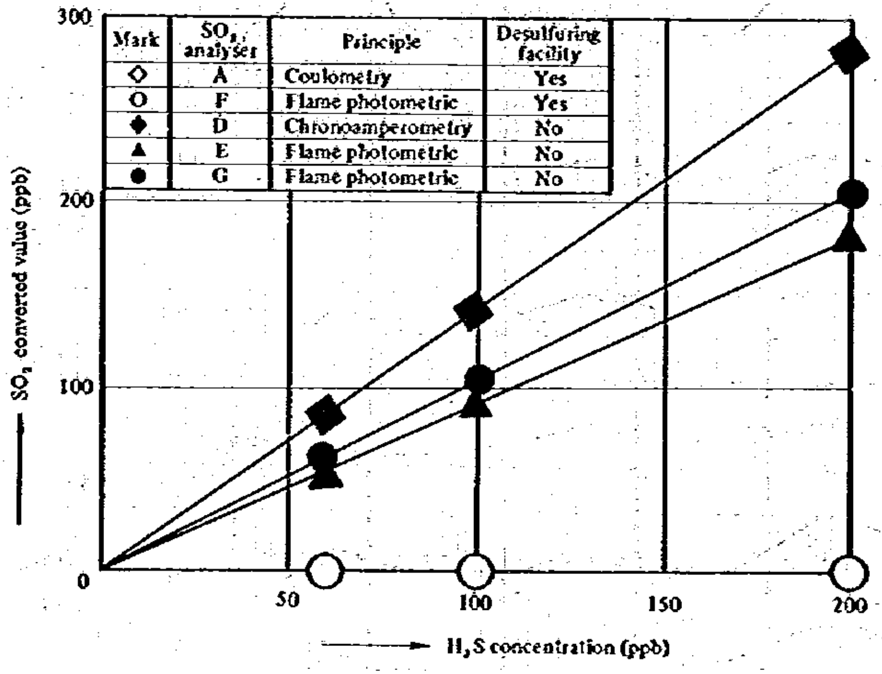

Fig. II-3-3 Impact of H_2S

II-3-2 SO_2 Analyzer Employed in the Study

In Japan, the measuring method of ambient SO_2 concentration is regulated to employ solution conductmetry. Although the method has a disadvantage of having tendency to be affected by alkali substances like ammonia, but it has many advantages, such as;

(1) minimum measuring range (0 to 50 ppb) is smaller than other methods,

(2) automatic zero adjustment system is installed,

(3) durability for long term operation is superior,

(4) calibration can be performed by equivalent solution which is far easier than that of other methods.

By the above reasons, SO_2 analyzers based on solution conductmetry have been employed in this environmental study.

There are 3 manufacturers of SO_2 analyzer in Japan, but DKK (DENKI KAGAKU KOGYO) has been selected from their past records and contribution. The specifications are shown in Table II-3-3 and Picture II-3-1 shows its outside view.

The analyzer is to detect and indicate automatically and continuously SO_2 ambient concentration by passing a fixed amount of sample air into a fixed amount of solution for a fixed period of time and measuring the increase of conductivity of the solution which is corresponding to the concentration. The value indicated at the end of one cycle time (one hour) shows one hour average of SO_2 concentration.

The absorbing solution is 0.006% hydrogen peroxide solution which includes sulfuric acid of 1×10^{-5}N. The analyzer is designed to pass 1 liter/min. of sample air into 20 ml of solution for one hour. During one hour measurement, ample quantity of air can be collected and high sensitivity is secured which make possible to measure in small range of 0 to 0.05 ppb.

In the solution conductmetry SO_2 analyzer, it has the tendency that at its initial stage of measurement (zero point), the impact of temperature and solution of CO_2 are not negligible and so in order to avoid such influences, the automatic adjustment system is installed. As shown in Fig. II-3-4, the method is to measure the difference of conductivity between the initial conductivity at the measuring electrode and that of absorbing SO_2. The change of conductivity of the solution is compensated automatically by the thermistor. Together with the effective function of automatic adjustment system installed in the analyzer, the instruments are designed to prevent the interference of CO_2 and to provide the stable performance.

A study on interference substances has been conducted by ENVIRONMENT AGENCY, Japanese Government, as shown in Table II-3-4.[4)]

The result of the study enumerates Cl_2, HCl, HF, and NH_3 as the interference substances, but these are usually existing in the ambient in very small quantity except NH_3 and so no special consideration may be necessary.

In order to avoid NH_3, oxalic acid trap is usually installed at the sample inlet but as the oxalic acid sublimate at the temperature over 25°C, the arrangement has not been given to this particular study.

The comparison between solution conductmetry and parasosehiline method which is employed in USA.5) As shown in figure, the measured values by two methods are found well coincided.

Table II-3-3 Specifications of SO_2 analyzer used in this study

Name	Measuring instrument of ambient SO_2 concentration
Manufacturer	Denki Kagaku Keiki, KK
Type	GRH - 72
Objective pollutant	Ambient SO_2
Principle	Solution conductmetry
Measurement range	0-0.05, 0.1, 0.2, 0.5, 1 ppm 5 range automatic/manual change
Measurement cycle	60 minutes (switchable to 30 min.)
Recording	Saw-tooth dotted recording. Starting from zero and end of cycle indicates one hour average value
Sampling rate	1 liter/min.
Reagent quantity	20 ml
Reagent tank capacity	20 liter
Recording unit	Output; 0-1 VDC Recording; dotted saw-tooth recording, 25 mm/h Chart; folded strip, 180 mm width
Output voltage	DC 0-1 V
Power requirements	AC 100 V ±10%, 50 Hz or 60 Hz
Weight	about 110 kg (including 20 liter of reagent)
Dimension	460 (W) x 1580 (H) x 500 (D)
External colour	Munsell N4

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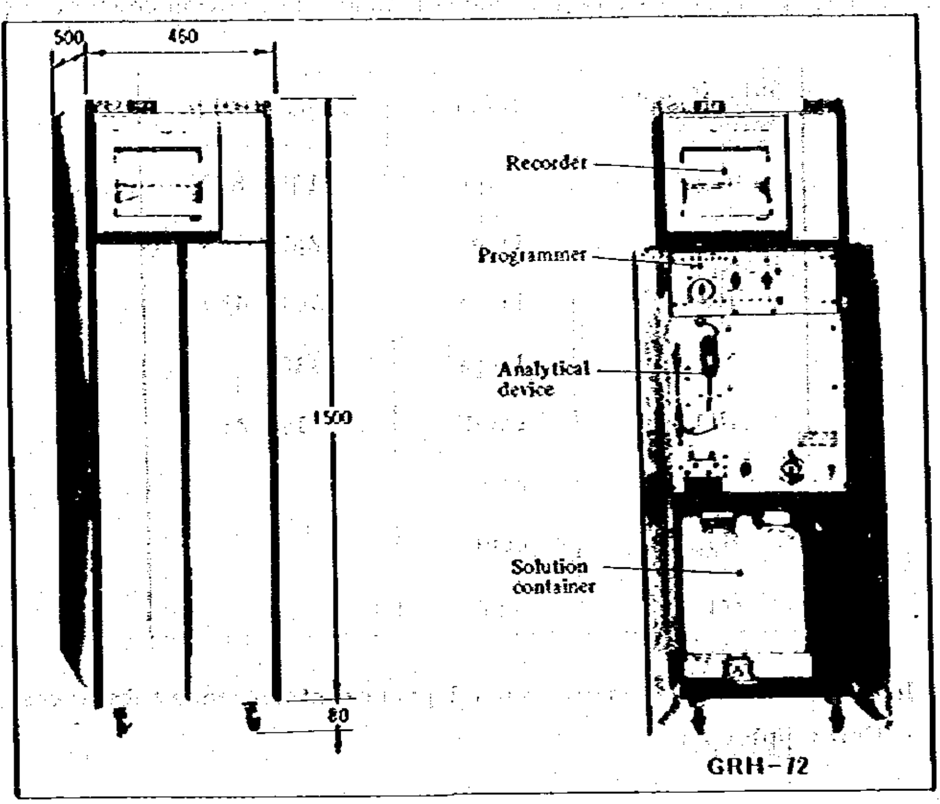
4) Environment Agency; Study on accuracy of automatic monitoring instruments, (1975)

5) Environment Agency; Study on measuring methods of ambient sulfur dioxide, (1975)



Picture II-3-1 Outside view of SO_2 analyzer used in this study

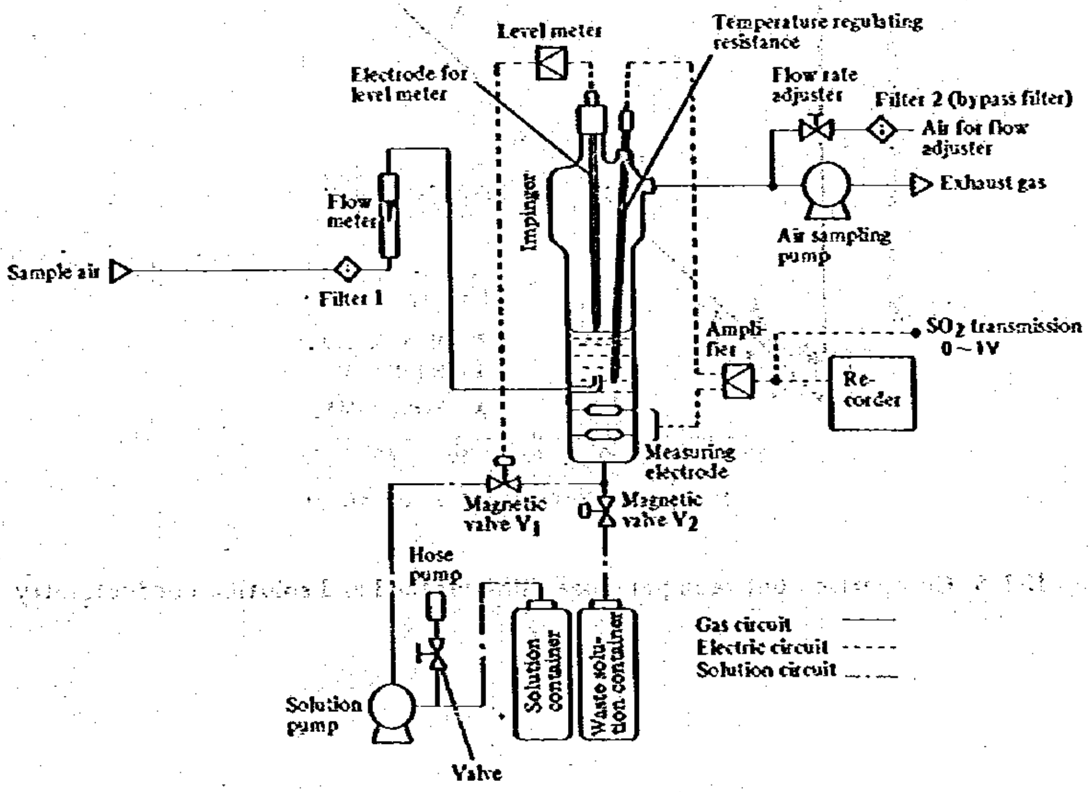


Fig. II-3-4 Flowchart of measurement of SO_2 analyzer

Table II-3-4 Impact of interference substances in solution conductmetry

Interference substances	Impact	Impact value*
Cl_2	large	180 - 800
HCl	large	287 - 508
HF	large	364 - 420
NH_3	large	330
NO_2	small	19 - 21
NO	none	-
H_2S	none	-
O_3	none	-

* Impact value (SO_2 converted) per 1 ppm of interference substances
Unit : ppb/ppm

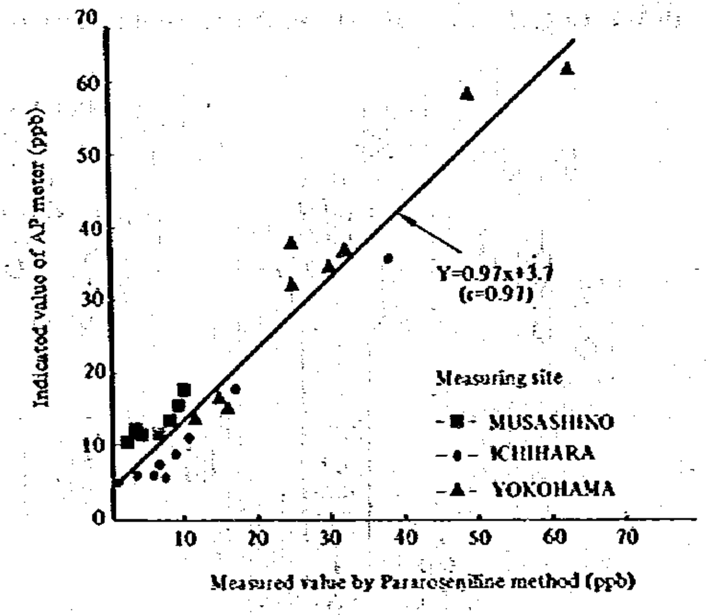


Fig. II-3-5 Comparison between pararosaniline method and solution conductmetry

II-3-3 Measuring Operation

SO_2 analyzer used in this study is based on one hour cycle and at its initial stage, the reagent (0.006 W/V% hydrogen peroxide including 1×10^{-5}N sulfuric acid) of 20 ml is automatically introduced into impinger when the reagent is designed to indicate zero by automatic zero adjustment system. In the next stage, the sample air is introduced by flow rate of 1 liter/min. The measurement of ambient SO_2 concentration is performed for 57.25 minutes converting the increase of conductivity into concentration.

The indicated value at the final stage of one cycle represents one hour average value of the cycle. After 57.25 minutes, the reagent is automatically exhausted out and new reagent is introduced for cleaning the inside of impinger which is finally exhausted out. These are the processes of one cycle measurement. These processes have been programmed as shown in Fig. II-3-6 by which continuous and automatic measurement is performed.

	1	2	3	4	5	6	7	8	9
Time (min.)	57.25	0.25	0.25	0.25	0.25	0.25	1.0	0.25	0.25
Operation	air flow	discharge solution	measurement	air flow	discharge solution	measurement	air flow	return auto-range	zero adjustment
V_1			▨			▨			
V_2		▨			▨				
Air pump	▨			▨			▨	▨	▨
Solution pump			▨			▨			
Return auto-range								▨	
SO_2 zero adjustment									▨
SO_2 hold		▨	▨	▨	▨	▨	▨	▨	▨

Fig. II-3-6 Program chart of SO_2 analyzer

II-3-3-1 Sampling tube

Teflon is used as the sampling tube which has inner diameter 6-8 mm, and length about 5 m. The end of Teflon tube is connected to the port marked GAS INLET of SO_2 analyzer as shown in Fig. II-3-7. A funnel is attached at the other end of tube, facing ground to avoid rain water.

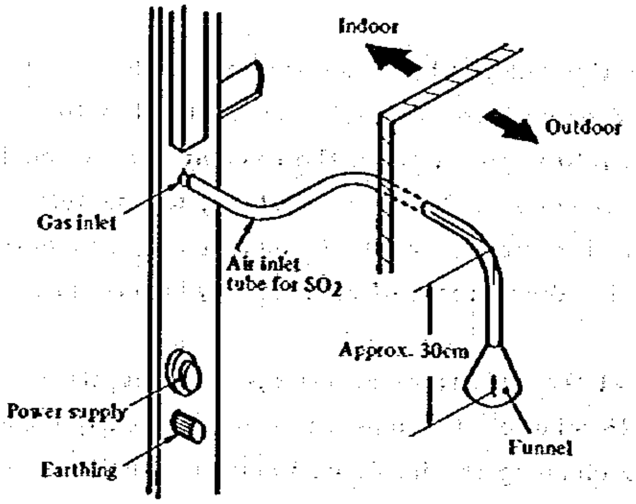


Fig. II-3-7 Installation of air inlet

II-3-3-2 Electrical connections

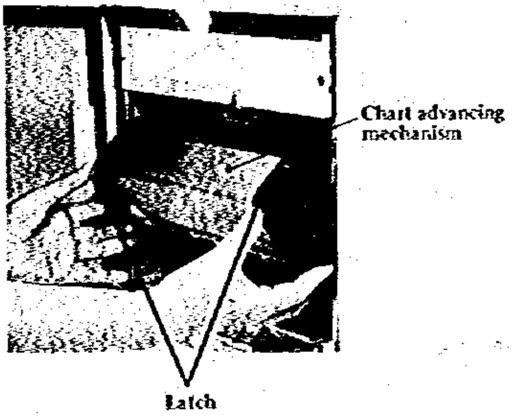
After confirming the consistency to the specifications in terms of voltage, frequency and capacity, the power cable is connected to the power connector located at the back side of analyzer. (In Singapore, power supply is based on 200 V and so used transformer to reduce the voltage). The earthing cable is connected with earth terminal which is also located at the back side of analyzer. The other end is securely grounded. Picture II-3-2 shows the locations of the above mentioned power cable connector and earth terminal.

Picture II-3-2 Connections of power cable and earth terminal

II-3-3-3 Chart loading

The chart loading is performed as follows:

(1) prepare chart (CH-5154-5) and ruffle to avoid sticking
(2) confirm power switch of the recording unit
(3) tilt the chart frame towards operator as shown in Picture II-3-3



Picture II-3-3 Loading of chart

(4) place the chart in the chart housing as shown in Fig. II-3-8, and draw out the chart to fit its perforation to the sprocket and then move back the frame to the original position
(5) erect the chart guide, advance the chart about 30 cm, fold it on the receiving plate and then move back the guide to the original position

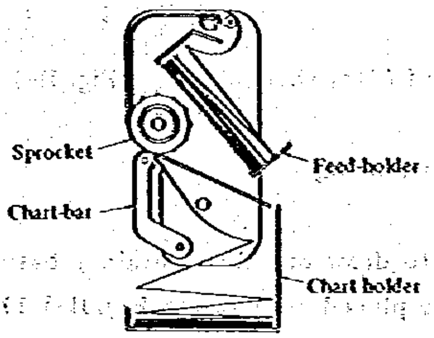


Fig. II-3-8 Loading of chart

(6) set the ink wheel on the holder as shown in Fig. II-3-9

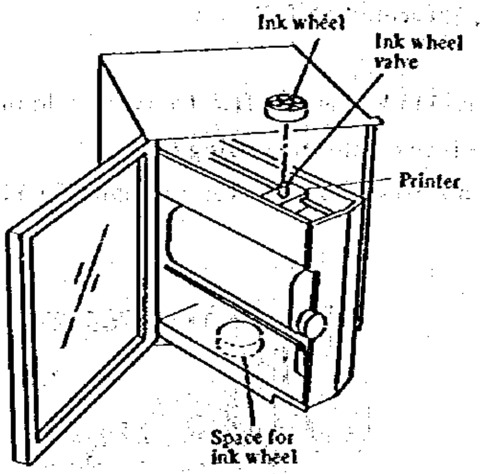
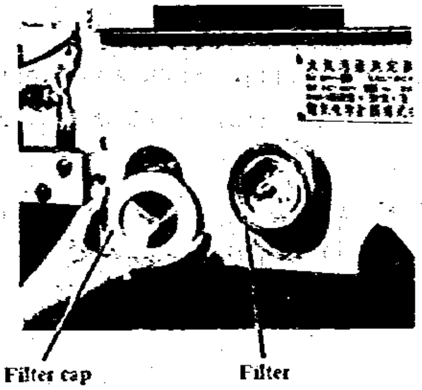


Fig. II-3-9 Loading of ink wheel

II-3-3-4 Filter loading

As shown in Fig. II-3-10 and Picture II-3-4, a filter sheet is loaded in the filter case.



Picture II-3-4 Loading of filter sheet

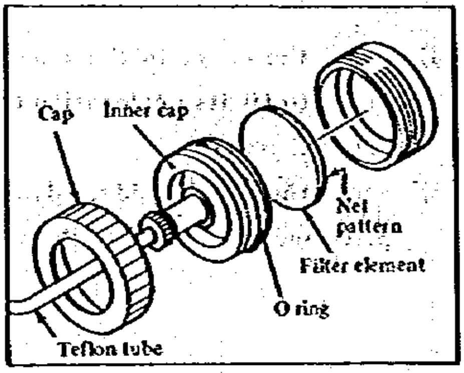


Fig. II-3-10 Loading of filter sheet

II-3-3-5 Solution container loading

The stopper is tilted to draw out the container base, and the empty container and reagent filled container are placed as shown in Fig. II-3-11 after tightly capped, and then replace the container base in the original position.

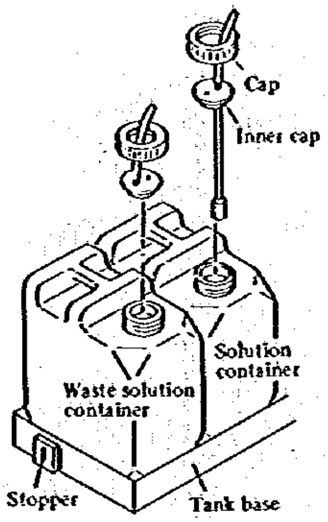


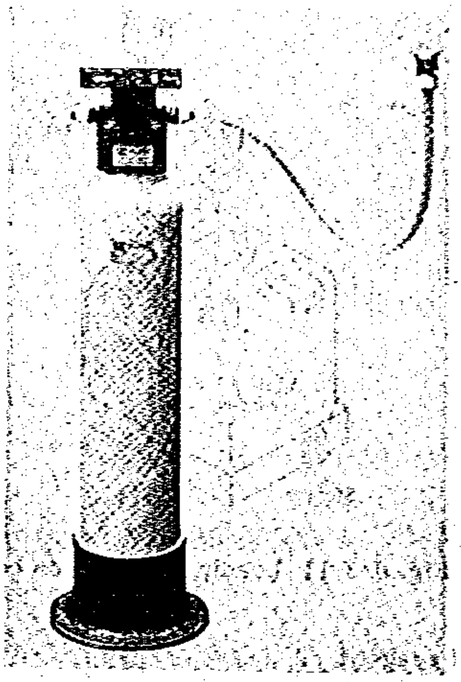
Fig. II-3-11 Loading of solution container

II-3-3-6 Preparation of reagent

The composition of the reagent is hydrogen peroxide of 0.006 W/V% containing sulfuric acid of 1×10^{-5}N. The reagent thus prepared is kept effective for 4 weeks and so once every 4 weeks the reagent has been prepared by JTC for replacement in this study. The processes of preparing reagent are as follows:

(1) prepare 20 liter distilled water in polyethylene container
(2) add 4 ml of 30%-H_2O_2
(3) further add 2 ml of 0.1N-H_2SO_4 in the same container
(4) shake the container for good mixing

The conductivity of reagent thus prepared is 4 μ℧/cm. The distilled water must have the conductivity of 1 μ℧/cm or less. In this study, the ion exchanger has been used to obtain the pure water of the above standard which had been brought from Japan. The out view and specifications of the ion exchanger are shown in Picture II-3-5 and Table II-3-5 respectively.



Picture II-3-5 Ion exchanger

Table II-3-5 Specifications of ion exchanger

Manufacturer	ORGANO CO., Ltd.
Type	G-10 type
Standard flow rate	50 - 200 liter/hour
Max. effective quantity	about 2,000 liter
Ion exchange resin	Manburlite MB-2 Resin-10 liter
Quality tester	Measuring range 0-2μ℧/cm, (battery usable)
Dimension (mm)	165φ x 905 H
Operation weight	17.5 kgs
Max. operation pressure	3.5 kg/cm^2

II-3-3-7 Calibration of instruments

By the processes described in the above, II-3-3-1 to II-3-3-6, the measurement of SO_2 ambient concentration is performed, but prior to the commencement of measurement, it is necessary to calibrate the instruments.

Due to the difficulty to obtain the standard gas of low concentrations, the calibration of instruments are carried out by preparing equivalent solution.

(1) Preparation of equivalent solution

(a) Chemical for equivalent solution (N/100 sulfuric acid)
N/10 sulfuric acid used for the preparation of reagent is diluted to 10 times by using pipet and mesh flask.

(b) Equivalent solution for zero adjustment
The reagent prepared as described in II-3-3-6 is used for zero adjustment

(c) Equivalent solution for span adjustment
As shown in Table II-3-6, the equivalent solution is prepared corresponding to the concentrations of SO_2, using pipet and mesh flask.

Table II-3-6 Chemical for equivalent solution and corresponding SO_2 concentration

Chemical quantity for equivalent solution	Corresponding SO_2 concentration	Measuring range
0.5 ml	0.021 ppm	
1.0 ml	0.042 ppm	0.05 ppm
2.0 ml	0.084 ppm	0.1 ppm
4.0 ml	0.168 ppm	0.2 ppm
10.0 ml	0.420 ppm	0.5 ppm
20.0 ml	0.839 ppm	1.0 ppm

(2) Preparation for calibration

The span adjustment of each range and zero adjustment solution are prepared, pouring into nozzled bottle of 1 liter. The solution is injected into the impinger from solution filling mouth, taking off the rubber stopper, and flow the solution to the end of level detector rod and thermistor, as shown in Fig. II-3-12.

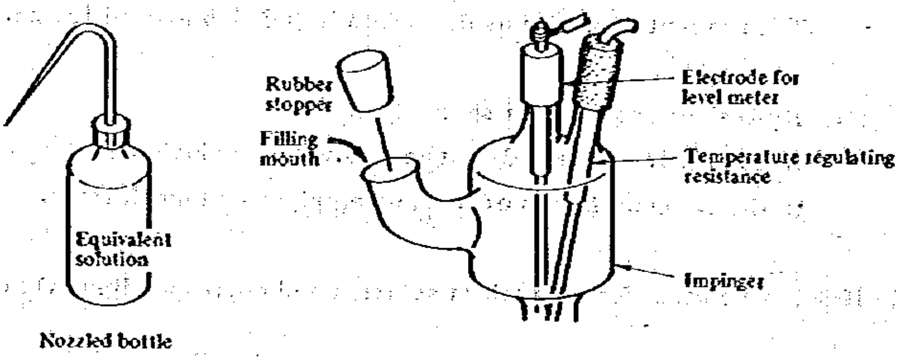


Fig. II-3-12 Filling of equivalent solution

(3) Zero adjustment

Zero adjustment is carried out by the following processes.

(a) Set the measuring range to the maximum (0-50 ppb), inject 0 ppm equivalent solution into the impinger, set the function selector to SOL.DISCHARGE and lock the MANUAL switch to drain the impinger. Repeat the same steps 3 or 4 times to clean up the inside of impinger.

(b) Charge the impinger with zero equivalent solution, set the function selector to ZERO ADJUST and lock the MANUAL for 30 seconds.

(c) Set the function selector to MEASURE and lock the MANUAL. Verify the recorder reads zero and unlock the MANUAL. If zero is not read, adjust SO_2 zero trimpot so as to read zero.

(d) Set the function selector to SOL.DISCHARGE and lock the MANUAL. After the impinger is completely drained, unlock the MANUAL.

(4) Span adjustment

The span adjustment is carried out by the following processes.

(a) Inject 20 ml of equivalent solution into the impinger from the filling mouth.

(b) Set the function selector to SOL.DISCHARGE and lock the MANUAL for 20 seconds to drain the impinger.

(c) Repeat the above (a) and (b) three or four times.

(d) Inject 20 ml of equivalent solution.

(e) After 30 seconds, set the function selector to MEASURE and lock the MANUAL. Verify the recorder reads the corresponding concentration of the equivalent solution before unlock the MANUAL. If the recorder indication deviates from the correct value, adjust the SPAN trimpot for the selected range.

(f) Check and correct other ranges as described in the above.

(g) For the adjustment of intermediate concentration, do not set the function selector.

(h) After span adjustment is completed, empty the drain tank to avoid overflowing.

II-3-3-8 Operation of hose pump

The operation of hose pump is to verify that absorbing solution is sent to the impinger automatically and in regular flow rate. The processes are as follows.

(a) Set the function selector to HOSE PUMP and lock the MANUAL.

(b) Open 2-way cock as shown in Fig. II-3-13 and push the hose pump by manual, and verify that solution is sent to the impinger.

(c) Close the 2-way cock and unlock the MANUAL. Confirm the bubbles in the tube.

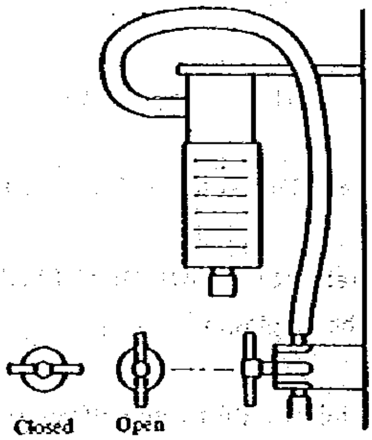


Fig. II-3-13 Operation of hose pump

II-3-3-9 Adjustment of flow meter

Set the function selector to AIR FLOW and lock the MANUAL. Adjust the flow meter by valve as shown in Fig. II-3-14.

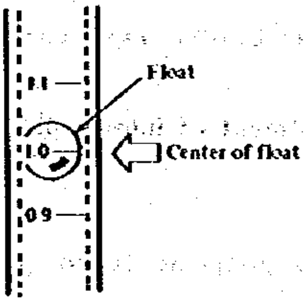


Fig. II-3-14 Adjustment of flow meter

II-3-3-10 Automatic measurement

Set the function selector to AUTO and confirm the light of auto measurement indicator. Keep the MANUAL in OFF position. Set SO_2 range selector on the programmer panel to AUTO and confirm the light of auto-range indicator. Set the timer on the programmer panel to the present time, as shown in Fig. II-3-15, by turning its knob clockwise. Turn on the recorder power switch and send out the chart by means of chart advance knob until the recorder pen dots the present time on the chart.

After the above processes, the analyzer is in automatic operation by the program shown in Fig. II-3-6.

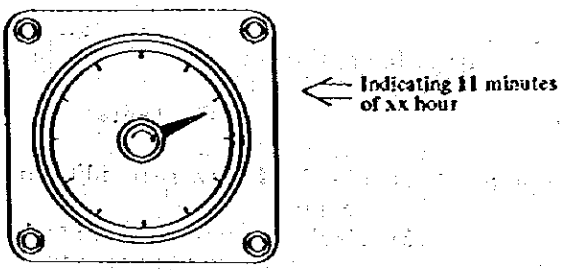


Fig. II-3-15 Adjustment of timer

II-3-3-11 Maintenance of SO_2 analyzer

The proper maintenance of instruments is absolutely necessary to secure the accuracy of measurement extending for long term by proper and sound operation of instrument.

Table II-3-7 shows standard items and frequency necessary for the maintenance.

Table II-3-7 Items and frequency for maintenance of SO_2 analyzer

No.	Item for maintenance		Frequency							
	Item	Contents	1 w.	2 w.	1 m.	2 m.	3 m.	4 m.	6 m.	1 y.
1	Air sampling tube	1) dirt, leakage, damage, disconnection			x					
		2) rinsing of tube inside					x			
		3) replacement of tube								x
2	Air passage except sampling tube	1) dirt, leakage, damage, disconnection	x							
		2) rinsing of connector & inside tube					x			
		3) replacement of tube								x
		4) test for gas leakage					x			
3	Solution passage	1) dirt, leakage, damage, disconnection		x						
		2) rinsing of connector & inside tube					x			
		3) replacement of tube								x
4	Flow meter	1) dirt & dust of inside, position of float	x							
		2) adjustment to 1.0 liter/min.	x							
		3) rinsing of inside and float					x			
		4) check indication of flow rate							x	

Note: w.: week, m.: month y.: year

Table II-3-7 Items and frequency for maintenance of SO_2 analyzer (Cont'd)

No.	Item for maintenance		Frequency							
	Item	Contents	1 w.	2 w.	1 m.	2 m.	3 m.	4 m.	6 m.	1 y.
5	Flow rate adjustment valve	1) check of flow rate adjustment range	x							
		2) rinsing of needle and inside					x			
6	Filter(1) Element	1) replacement of element	x							
	Case	2) rinsing of inside and connector					x			
		3) replacement of filter case								x
7	Absorbing solution	preparation of solution and replacement		x						
8	Gas absorbing system	1) dirt, bubbling	x							
		2) rinsing of inside and electrode					x			
9	Air absorbing pump	1) abnormal noise and vibration, check of flow rate			x					
		2) rinsing of diaphragm, valve & joint					x			
		3) replacement of diaphragm and valve								x
10	Solenoid valve	check of opening & closing operation					x			
11	Solution charging pump	1) abnormal noise and vibration		x						
		2) check of flow rate			x					
12	Solution in impinger	1) check solution quantity as 20±0.4 ml					x			
		2) adjustment of electrode for level detector					x			
13	Calibration by equivalent solution	calibration of each range by equivalent solution					x			
14	Recorder chart	1) proper advance	x							
		2) check of chart slip	x							
		3) replacement of chart			x					
	ink	4) shade of ink	x							
		5) supply of ink		x						
	indicator	6) zero adjustment								x
15	Timer	check of time gap	x							
16	Power source, earth	check loosing, disconnection, brokage		x						
17	Adjustment of electronic circuit	adjustment of slide, range, balance, D/A								x
18	Filter(2) by-path filter	replacement of element								x

II-3-4 Maintenance and Results of Measurement

At 7 monitoring stations enumerated in Table II-1-1, the automatic and continuous measurement of SO_2 ambient concentration has been carried out for one year, from July 15th 1981 to July 14th 1982. The maintenance of instruments have been conducted by JURONG TOWN CORPORATION (JTC) through the year and the calibration has been carried out by Japanese team for 3 times within the above period.

The maintenance and the results of measurement are described.

II-3-4-1 Maintenance

(1) Regular maintenance

Based on the items and frequency of maintenance of SO_2 analyzer shown in Table II-3-7, SO_2 analyzers installed in monitoring stations have been maintained by JTC for the items mentioned hereunder.

(a) check of dirt, leakage, damage and disconnection of sampling tube
(b) check of dirt, leakage, damage and disconnection of air passage
(c) check of dirt, leakage, damage and disconnection of solution passage
(d) check of dirt and dust of inside of flow meter
(e) check of float position
(f) adjustment of flow rate (1 liter/min.)
(g) check of dirt and bubbling of gas absorbing system
(h) check and adjustment of chart advance
(i) adjustment of time gap of chart
(j) check of ink shade
(k) adjustment of time gap of timer

Besides the above, the filter has been replaced once a week as described in II-3-3-4, the absorbing solution has been prepared and replaced once for 2 weeks as described in II-3-3-6, and the chart has been replaced once a month as described in II-3-3-3.

(2) Calibration of SO_2 analyzer

In order to secure the sound and proper operation of SO_2 analyzer and accuracy of measurement, the calibration has been conducted once every 3 months as shown in Table II-3-8. The calibration has been performed by equivalent solution as described in II-3-3-7.

In parallel with the calibration by equivalent solution, the following items have been checked and maintained according to the report form shown in Table II-3-9.

(a) rinsing or replacement of sampling tube
(b) rinsing of connector of gas passage and inside of tube
(c) leakage test of gas passage
(d) rinsing or replacement of connector of solution passage and inside of the tube
(e) rinsing of inside and float of flow meter
(f) check of indicator of flow meter
(g) rinsing of filter case
(h) rinsing of impinger
(i) rinsing of air absorbing pump
(j) check of solenoid valve operation
(k) check of solution charging pump
(l) check and adjustment of solution quantity of impinger

Table II-3-8 Data of calibration of SO_2 analyzer

Station	1st calibration	2nd calibration	3rd calibration	4th calibration	5th calibration
MP-1	June 25th, '81	Oct. 27th, '81	Feb. 2nd, '82	May 25th, '82	July 19th, '82
MP-2	June 29th, '81	Oct. 26th, '81	Feb. 5th, '82	May 24th, '82	July 16th, '82
MP-3	June 26th, '81	Oct. 26th, '81	Feb. 5th, '82	May 24th, '82	July 17th, '82
MP-4	July 1st, '81	Oct. 27th, '81	Feb. 3rd, '82	May 26th, '82	July 20th, '82
MP-5	June 30th, '81	Oct. 27th, '81	Feb. 3rd, '82	May 26th, '82	July 20th, '82
MP-6	July 2nd, '81	Oct. 29th, '81	Feb. 4th, '82	May 27th, '82	July 21st, '82
MP-7	July 3rd, '81	Oct. 29th, '81	Feb. 4th, '82	May 27th, '82	July 21st, '82

Table II-3-9 SO_2 analyzer maintenance report form

Type. GRH-72 SER. NO. Station: MP-

Maintenance items			Reference section
Sampling tube cleaning	Yes	No	II-3-5 (1)
Sampling paths within analyzer cleaning	Yes	No	II-3-5
Sample leak test	Good	No	II-3-9
Solution path tubes cleaning	Yes	No	II-3-11
Flow meter cleaning	Yes	No	II-3-6 (1)
Flow meter calibration	Yes	No	II-3-6 (2)
Flow control valve cleaning	Yes	No	II-3-7
Filter case cleaning	Yes	No	II-3-5 (2)
Impinger cleaning	Yes	No	II-3-4
Sampling pump cleaning	Yes	No	II-3-3
Solenoid valve inspection	Good	No	
Solution pump inspection	Good	No	II-3-10
Confirmation and adjustment of reagent quantity in impinger	Within 20 ±0.4 ml Good	No	II-3-8
Calibration with equivalent solution	Good	No	I-4-3
Remarks:			

Calibration with equivalent solution

Standard (SO_2 ppm)	Indication (SO_2 ppm)			
	0.05 Range	0.10 Range	0.20 Range	0.50 Range
0.000	0.000	0.000	0.000	0.000
0.021				
0.042				
0.084				
0.168				
0.420	before adj. after adj.			

Month/day /

Weather

Surveyor

The results of calibration of SO_2 analyzers installed in 7 monitoring stations, MP-1 to MP-7, are shown in Table II-3-10-(1) to -(8). The prior calibration in the table means the calibration by adjusting SO_2 indicated concentration with equivalent solution, introducing equivalent solution of about 90% concentration of maximum range. And post calibration means the calibration by checking SO_2 indicated concentration with equivalent solution prepared in same way with prior calibration after certain period (3 months in this study) of measurement of ambient air.

Table II-3-10-(1) Results of calibration by equivalent solution (1st calibration, prior calibration)

SO_2 analyzer	Range (ppm)	Equivalent solution concentration (ppb)					
		0	21	42	84	168	420
MP-1	0.50	-	-	-	-	-	-
	0.20	0	-	-	83	168*	###
	0.10	0	-	41	84*	###	###
	0.05	0	19.5	42*	###	###	###
MP-2	0.50	-	-	-	-	-	-
	0.20	0	-	-	85	168*	###
	0.10	0	-	41.7	84*	###	###
	0.05	0	20.5	42*	###	###	###
MP-3	0.50	-	-	-	-	-	-
	0.20	0	20.0	-	83	166*	###
	0.10	0	20.5	41	83*	###	###
	0.05	0	20.0	42*	###	###	###
MP-4	0.50	0	-	-	-	168	415*
	0.20	0	-	-	82	167*	###
	0.10	0	-	41.5	83*	###	###
	0.05	0	20.5	42.4*	###	###	###
MP-5	0.50	-	-	-	-	-	-
	0.20	0	21	42	83	168*	###
	0.10	0	-	41	83*	###	###
	0.05	0	19.7	42*	###	###	###
MP-6	0.50	-	-	-	-	-	-
	0.20	0	21	42	87	168*	###
	0.10	0	21	42	84*	###	###
	0.05	0	21	42*	###	###	###
MP-7	0.50	-	-	-	-	-	-
	0.20	0	-	-	84	166*	###
	0.10	0	-	42	84*	###	###
	0.05	0	20.3	42.5*	###	###	###

* : Span adjustment

Table II-3-10-(2) Results of calibration by equivalent solution
(2nd calibration, post calibration)

SO_2 analyzer	Range (ppm)	Equivalent solution concentration (ppb)					
		0	21	42	84	168	420
MP-1	0.50	0	-	-	-	-	415
	0.20	0	20	41	82	168	###
	0.10	0	-	-	83.7	###	###
	0.05	0	21	42	###	###	###
MP-2	0.50	0	-	-	-	-	409
	0.20	0	-	-	-	164	###
	0.10	0	-	-	80	###	###
	0.05	0	-	40	###	###	###
MP-3	0.50	0	21	42	82	167	420
	0.20	0	-	-	-	166	###
	0.10	0	-	-	83	###	###
	0.05	0	-	41	###	###	###
MP-4	0.50	0	20	42	84	168	420
	0.20	0	20	42	83	168	###
	0.10	0	21	42	84	###	###
	0.05	0	-	42.5	###	###	###
MP-5	0.50	0	21	42	84	168	420
	0.20	0	21	42	83	168	###
	0.10	0	-	-	83.5	###	###
	0.05	0	-	42.3	###	###	###
MP-6	0.50	0	-	-	-	-	438
	0.20	0	-	-	-	176	###
	0.10	0	-	-	87	###	###
	0.05	0	-	44	###	###	###
MP-7	0.50	0	-	-	-	-	415
	0.20	0	-	-	-	167	###
	0.10	0	-	-	83.5	###	###
	0.05	0	-	42.3	###	###	###

Table II-3-10-(3) Results of calibration by equivalent solution (2nd calibration, prior calibration)

SO_2 analyzer	Range (ppm)	Equivalent solution concentration (ppb)					
		0	21	42	84	168	420
MP-1	0.50	0	20	40	83	168	420*
	0.20	0	20	41	82	168*	###
	0.10	0	21	41.5	84*	###	###
	0.05	0	21	42*	###	###	###
MP-2	0.50	0	20	40	83	167	420*
	0.20	0	20	41	83	168*	###
	0.10	0	20.5	42	84*	###	###
	0.05	0	21	42*	###	###	###
MP-3	0.50	0	21	42	82	167	420*
	0.20	0	21	41	83	168*	###
	0.10	0	21	41.5	84*	###	###
	0.05	0	21	42*	###	###	###
MP-4	0.50	0	20	42	84	168	420*
	0.20	0	20	42	83	168*	###
	0.10	0	21	42	84*	###	###
	0.05	0	21	42*	###	###	###
MP-5	0.50	0	21	42	84	168	420*
	0.20	0	21	42	83	168*	###
	0.10	0	21	41.5	84*	###	###
	0.05	0	21	42*	###	###	###
MP-6	0.50	0	20	42	84	169	420*
	0.20	0	20	42	83	168*	###
	0.10	0	21	42.3	84*	###	###
	0.05	0	21.5	42*	###	###	###
MP-7	0.50	0	22	43	84	167	420*
	0.20	0	21	42	84	168*	###
	0.10	0	20.5	42	84*	###	###
	0.05	0	21	42*	###	###	###

* : Span adjustment

Table II-3-10-(4) Results of calibration by equivalent solution
(3rd calibration, post calibration)

SO_2 analyzer	Range (ppm)	Equivalent solution concentration (ppb)					
		0	21	42	84	168	420
MP-1	0.50	0	20	41	82	167	419
	0.20	0	21	41	82	167	###
	0.10	0	21	41.8	83	###	###
	0.05	0	21.2	42	###	###	###
MP-2	0.50	0	22	42	83	168	422
	0.20	0	-	-	-	170	###
	0.10	0	21.4	42.5	84.4	###	###
	0.05	0	-	43.8	###	###	###
MP-3	0.50	0	-	-	-	-	413
	0.20	0	-	-	-	163	###
	0.10	0	-	-	80.5	###	###
	0.05	0	-	40.8	###	###	###
MP-4	0.50	0	21	42	82	167	417
	0.20	0	-	-	-	164	###
	0.10	0	-	-	82	###	###
	0.05	0	21.5	41.3	###	###	###
MP-5	0.50	0	20	43	86	169	418
	0.20	0	21	42	83	168	###
	0.10	0	-	-	82	###	###
	0.05	0	-	41.5	###	###	###
MP-6	0.50	0	21	42	84	170	425
	0.20	0	21	42	83	169	###
	0.10	0	21.4	42.4	84	###	###
	0.05	0	21.3	41.8	###	###	###
MP-7	0.50	0	-	-	-	-	414
	0.20	0	-	-	-	161	###
	0.10	0	-	-	81.5	###	###
	0.05	0	-	41	###	###	###

Table II-3-10-(5) Results of calibration by equivalent solution (3rd calibration, prior calibration)

SO_2 analyzer	Range (ppm)	Equivalent solution concentration (ppb)					
		0	21	42	84	168	420
MP-1	0.50	0	20	41	82	167	419*
	0.20	0	21	41	82	167*	###
	0.10	0	21	41.8	83*	###	###
	0.05	0	21.2	42*	###	###	###
MP-2	0.50	0	22	42	83	168	422*
	0.20	0	21	41.5	83	168*	###
	0.10	0	21.4	42.5	84.4*	###	###
	0.05	0	21.2	42*	###	###	###
MP-3	0.50	0	21	42	82	167	420*
	0.20	0	20.5	41	82.5	168*	###
	0.10	0	21	42	84*	###	###
	0.05	0	20.8*	42*	###	###	###
MP-4	0.50	0	21	42	82	167	417*
	0.20	0	21	42	83	168*	###
	0.10	0	21.5	42.2	84*	###	###
	0.05	0	21.5	41.3*	###	###	###
MP-5	0.50	0	20	43	86	169	418*
	0.20	0	21	42	83	168*	###
	0.10	0	21	42	84*	###	###
	0.05	0	21	42*	###	###	###
MP-6	0.50	0	21	42	84	170	425*
	0.20	0	21	42	83	169*	###
	0.10	0	21.4	42.4	84*	###	###
	0.05	0	21.3	41.8*	###	###	###
MP-7	0.50	0	22	42	83	164	420*
	0.20	0	21	42	83	168*	###
	0.10	0	21	42	84*	###	###
	0.05	0	21	42*	###	###	###

* : Span adjustment

Table II-3-10-(6) Results of calibration by equivalent solution (4th calibration, post calibration)

SO_2 analyzer	Range (ppm)	Equivalent solution concentration (ppb)					
		0	21	42	84	168	420
MP-1	0.50	0	-	-	-	-	412
	0.20	0	-	-	-	161	###
	0.10	0	-	-	81	###	###
	0.05	0	-	41	###	###	###
MP-2	0.50	0	21	42	83	167	417
	0.20	0	21	42	84	167	###
	0.10	0	21.2	43	85	###	###
	0.05	0	21.3	42.2	###	###	###
MP-3	0.50	0	20	41	82	167	418
	0.20	0	20.5	41.5	83	169	###
	0.10	0	-	-	83	###	###
	0.05	0	-	42.8	###	###	###
MP-4	0.50	0	21	42	82	167	420
	0.20	0	-	-	-	165	###
	0.10	0	21.7	42.1	84	###	###
	0.05	0	21.3	41.5	###	###	###
MP-5	0.50	0	21	42	83	167	417
	0.20	0	21	42.5	84	167	###
	0.10	0	21.6	43.3	84	###	###
	0.05	0	21.5	41.6	###	###	###
MP-6	0.50	0	-	-	-	-	431
	0.20	0	20	40.5	83	168	###
	0.10	0	20	41	83.5	###	###
	0.05	0	-	41.5	###	###	###
MP-7	0.50	0	-	-	-	-	428
	0.20	0	24	46	87	169	###
	0.10	0	23	44	83.5	###	###
	0.05	0	21.7	41.7	###	###	###

Table II-3-10-(7) Results of calibration by equivalent solution
(4th calibration, prior calibration)

SO_2 analyzer	Range (ppm)	Equivalent solution concentration (ppb)					
		0	21	42	84	168	420
MP-1	0.50	0	19	40	82	165	420*
	0.20	0	20	41	83	168*	###
	0.10	0	20	41.5	84*	###	###
	0.05	0	20.4	42*	###	###	###
MP-2	0.50	0	21	42	83	167	417*
	0.20	0	21	42	84	167*	###
	0.10	0	21.2	43	85*	###	###
	0.05	0	21.3	42.2*	###	###	###
MP-3	0.50	0	20	41	82	167	418*
	0.20	0	20.5	41.5	83	169*	###
	0.10	0	21	42.5	84*	###	###
	0.05	0	20.5	42*	###	###	###
MP-4	0.50	0	21	42	82	167	420*
	0.20	0	21	42.2	83	168*	###
	0.10	0	21.7	42.1	84*	###	###
	0.05	0	21.3	41.5*	###	###	###
MP-5	0.50	0	21	42	83	167	417*
	0.20	0	21	42.5	84	167*	###
	0.10	0	21.6	43.3	84*	###	###
	0.05	0	21.5	41.6*	###	###	###
MP-6	0.50	0	19	39	82	166	420*
	0.20	0	20	40.5	83	168*	###
	0.10	0	20	41	83.5*	###	###
	0.05	0	20.5	42*	###	###	###
MP-7	0.50	0	22	43	89	178	420*
	0.20	0	24	46	87	169*	###
	0.10	0	23	44	83.5*	###	###
	0.05	0	21.7	41.7*	###	###	###

* : Span adjustment

Table II-3-10-(8). Results of calibration by equivalent solution
(5th calibration, post calibration)

SO_2 analyzer	Range (ppm)	Equivalent solution concentration (ppb)					
		0	21	42	84	168	420
MP-1	0.50	0	20	41	81	164	422
	0.20	0	20	41.5	82	168	###
	0.10	0	-	-	83	###	###
	0.05	0	20.7	41.7	###	###	###
MP-2	0.50	0	-	-	-	-	410
	0.20	0	-	-	-	163	###
	0.10	0	-	-	81.2	###	###
	0.05	0	-	41.4	###	###	###
MP-3	0.50	0	21	41	80	163	417
	0.20	0	-	-	-	165	###
	0.10	0	-	-	82	###	###
	0.05	0	20.7	42	###	###	###
MP-4	0.50	0	20	42	82	167	417
	0.20	0	21	42	83.5	168	###
	0.10	0	-	-	82.3	###	###
	0.05	0	-	41.2	###	###	###
MP-5	0.50	0	-	-	-	-	415
	0.20	0	-	-	-	166	###
	0.10	0	21	42.2	83	###	###
	0.05	0	21	42	###	###	###
MP-6	0.50	0	18	39	79	165	420
	0.20	0	20	41	81	168	###
	0.10	0	-	-	81.4	###	###
	0.05	0	-	41	###	###	###
MP-7	0.50	0	-	-	-	-	409
	0.20	0	-	-	-	164	###
	0.10	0	-	-	80	###	###
	0.05	0	-	39.8	###	###	###

In order to verify the relation between concentrations of equivalent solution and indicating value of SO_2 analyzer, the following factors have been investigated as shown in Table II-3-11-(1) to -(8).

(a) Linear regression equation ($y = ax + b$)
when x = equivalent solution concentration (ppb)
y = indicating concentration of SO_2 analyzer (ppb)
(b) Correlation coefficient (r)
(c) Deviation from regression equation (σe)
(d) Deviation from $y=x$ $\left(\frac{\text{max. deviation from } y=x \text{ (ppb)}}{\text{full scale range (ppb)}} \times 100\right)$

The illustrated linear regression equations are shown in ANNEX. The correlation coefficient (r) is expressed quantitatively the correlation between valuables x and y, by Equation II-3-1 and is obtained in the range "$-1 \leq r \leq 1$".

When $r=1$ or $r=-1$, all the dots on the scatter diagram are illustrated on the certain line and when r is near to 1 or -1, all the dots are gathered on or around the certain line. On the contrary, r is near to zero, these dots on the scatter diagram are scattering in different directions which means there are few correlation among factors. Further, when $r>0$, correlation exists in positive side and when $r<0$, it is in negative side.

$$r = \frac{Sxy}{\sqrt{Sxx \cdot Syy}}$$

Equation II-3-1

$$\left[\begin{array}{l} Sxx = \Sigma x^2 - \frac{(\Sigma x)^2}{n} \\ \\ Syy = \Sigma y^2 - \frac{(\Sigma y)^2}{n} \\ \\ Sxy = \Sigma xy - \frac{\Sigma x \cdot \Sigma y}{n} \end{array}\right]$$

When: Σx, Σy ; total sum of sample (x), (y)
Σx^2, Σy^2 ; square sum of sample (x), (y)
Σxy ; sum of products of sample (x, y)
n ; number of samples

The deviation from regression equation, σe, is expressed quantitatively by applying Equation II-3-2 to the regression equation and variables (x_i, y_i). Smaller σe are confirmed that each variable is near linear regression equation.

$$\sigma_E = \sqrt{\frac{\sum_{i=1}^{n} \{yi - (axi + b)^2\}}{n-1}}$$

Equation II-3-2

Table II-3-11-(1) Correlation between concentrations of equivalent solution and SO_2 analyzer indication at calibration (1st calibration, prior calibration)

SO_2 analyzer	Range (ppm)	Parameter	Regression equation y = ax + b		Correlation coefficient	Deviation from equation	Deviation from y=x
		n	a	b	r	σE	(%)
MP-1	0.50	-	-	-	-	-	-
	0.20	3	1.000	-0.3	0.999	0.577	0.5
	0.10	3	1.000	-0.3	0.999	0.577	1.0
	0.05	3	1.000	-0.5	0.999	0.866	3.0
MP-2	0.50	-	-	-	-	-	-
	0.20	3	1.000	0.3	0.999	0.577	0.5
	0.10	3	1.000	-0.1	0.999	0.173	0.3
	0.05	3	1.000	-0.2	0.999	0.289	1.0
MP-3	0.50	-	-	-	-	-	-
	0.20	4	0.990	-0.3	0.999	0.341	1.0
	0.10	4	0.988	-0.2	0.999	0.239	1.0
	0.05	3	1.000	-0.3	0.999	0.577	2.0
MP-4	0.50	3	0.988	0.8	0.999	1.147	1.0
	0.20	3	0.994	-0.5	0.999	0.866	1.0
	0.10	3	0.988	0.0	0.999	0.000	1.0
	0.05	3	1.010	-0.2	0.999	0.404	1.0
MP-5	0.50	-	-	-	-	-	-
	0.20	5	0.999	-0.1	0.999	0.440	0.5
	0.10	3	0.988	-0.2	0.999	0.289	1.0
	0.05	3	1.000	-0.4	0.999	0.751	2.6
MP-6	0.50	-	-	-	-	-	-
	0.20	5	1.004	0.4	0.999	1.321	1.5
	0.10	4	1.000	0.0	1.000	0.000	0
	0.05	3	1.000	0.0	1.000	0.000	0
MP-7	0.50	-	-	-	-	-	-
	0.20	2	0.988	0.3	0.999	0.577	1.0
	0.10	3	1.000	0.0	1.000	0.000	0
	0.05	3	1.012	-0.3	0.999	0.548	1.4

Table II-3-11-(2) Correlation between concentrations of equivalent solution and SO_2 analyzer indication at calibration (2nd calibration, post calibration)

SO_2 analyzer	Range (ppm)	Parameter	Regression equation y = ax + b		Correlation coefficient	Deviation from equation	Deviation from y=x
		n	a	b	r	σE	(%)
MP-1	0.50	2	0.988	0.0	0.999	0.000	1.0
	0.20	5	1.001	-0.9	0.999	0.833	1.0
	0.10	2	0.996	0.0	0.999	0.000	0.3
	0.05	3	1.000	0.0	1.000	0.000	0
MP-2	0.50	2	0.974	0.0	0.999	0.000	2.2
	0.20	2	0.976	0.0	0.999	0.000	2.0
	0.10	2	0.952	0.0	0.999	0.000	4.0
	0.05	2	0.952	0.0	0.999	0.000	4.0
MP-3	0.50	6	1.000	-0.5	0.999	0.836	0.4
	0.20	2	0.988	0.0	0.999	0.000	1.0
	0.10	2	0.988	0.0	0.999	0.000	1.0
	0.05	2	0.976	0.0	0.999	0.000	2.0
MP-4	0.50	6	1.001	-0.3	0.999	0.387	0.2
	0.20	5	1.001	-0.5	0.999	0.542	0.5
	0.10	4	1.000	0.0	1.000	0.000	0
	0.05	2	1.012	0.0	0.999	0.000	1.0
MP-5	0.50	6	1.000	0.0	1.000	0.000	0
	0.20	5	0.999	-0.1	0.999	0.440	0.5
	0.10	2	0.994	0.0	0.999	0.000	0.5
	0.05	2	1.007	0.0	0.999	0.000	0.6
MP-6	0.50	2	1.043	0.0	0.999	0.000	3.6
	0.20	2	1.048	0.0	0.999	0.000	4.0
	0.10	2	1.036	0.0	0.999	0.000	3.0
	0.05	2	1.048	0.0	0.999	0.000	4.0
MP-7	0.50	2	0.988	0.0	0.999	0.000	1.0
	0.20	2	0.994	0.0	0.999	0.000	0.5
	0.10	2	0.994	0.0	0.999	0.000	0.5
	0.05	2	1.007	0.0	0.999	0.000	0.6

Table II-3-11-(3) Correlation between concentrations of equivalent solution and SO_2 analyzer indication at calibration (2nd calibration, prior calibration)

SO_2 analyzer	Range (ppm)	Parameter	Regression equation $y = ax + b$		Correlation coefficient	Deviation from equation	Deviation from y=x
		n	a	b	r	σE	(%)
MP-1	0.50	6	1.002	-1.0	0.999	0.721	0.4
	0.20	5	1.001	-0.9	0.999	0.833	1.0
	0.10	4	0.999	-0.1	0.999	0.249	0.5
	0.05	3	1.000	0.0	1.000	0.000	0
MP-2	0.50	6	1.002	-1.1	0.999	0.679	0.4
	0.20	5	1.002	-0.8	0.999	0.524	0.5
	0.10	4	1.002	-0.2	0.999	0.239	0.5
	0.05	3	1.000	0.0	1.000	0.000	0
MP-3	0.50	6	1.000	-0.5	0.999	0.836	0.4
	0.20	5	1.000	-0.4	0.999	0.548	0.5
	0.10	4	0.999	-0.1	0.999	0.249	0.5
	0.05	3	1.000	0.0	1.000	0.000	0
MP-4	0.50	6	1.001	-0.3	0.999	0.387	0.2
	0.20	5	1.001	-0.5	0.999	0.542	0.5
	0.10	4	1.000	0.0	1.000	0.000	0
	0.05	3	1.000	0.0	1.000	0.000	0
MP-5	0.50	6	1.000	0.0	1.000	0.000	0
	0.20	5	0.999	-0.1	0.999	0.440	0.5
	0.10	4	0.999	-0.1	0.999	0.249	0.5
	0.05	3	1.000	0.0	1.000	0.000	0
MP-6	0.50	6	1.001	-0.1	0.999	0.604	0.2
	0.20	5	1.001	-0.5	0.999	0.542	0.5
	0.10	4	1.000	0.1	0.999	0.149	0.3
	0.05	3	1.000	0.2	0.999	0.289	1.0
MP-7	0.50	6	0.998	0.4	0.999	0.695	0.2
	0.20	5	1.000	0.0	1.000	0.000	0
	0.10	4	1.002	-0.2	0.999	0.239	0.5
	0.05	3	1.000	0.0	1.000	0.000	0

Table II-3-11-(4) Correlation between concentrations of equivalent solution and SO_2 analyzer indication at calibration (3rd calibration, post calibration)

SO_2 analyzer	Range (ppm)	Parameter	Regression equation y = ax + b		Correlation coefficient	Deviation from equation	Deviation from y=x
		n	a	b	r	σE	(%)
MP-1	0.50	6	0.999	-0.9	0.999	0.623	0.4
	0.20	5	0.993	-0.4	0.999	0.670	1.0
	0.10	4	0.988	0.2	0.999	0.159	1.0
	0.05	3	1.000	0.1	0.999	0.115	0.4
MP-2	0.50	6	1.004	-0.2	0.999	0.781	0.4
	0.20	2	1.012	0.0	0.999	0.0	1.0
	0.10	4	1.004	0.2	0.999	0.171	0.5
	0.05	2	1.043	0.0	0.999	0.000	3.6
MP-3	0.50	2	0.983	0.0	0.999	0.000	1.4
	0.20	2	0.970	0.0	0.999	0.000	2.5
	0.10	2	0.958	0.0	0.999	0.000	3.5
	0.05	2	0.971	0.0	0.999	0.000	2.4
MP-4	0.50	6	0.993	-0.1	0.999	0.635	0.6
	0.20	2	0.976	0.0	0.999	0.000	2.0
	0.10	2	0.976	0.0	0.999	0.000	2.0
	0.05	3	0.983	0.3	0.999	0.491	1.4
MP-5	0.50	6	0.995	0.8	0.999	1.255	0.4
	0.20	5	0.999	-0.1	0.999	0.440	0.5
	0.10	2	0.976	0.0	0.999	0.000	2.0
	0.05	2	0.988	0.0	0.999	0.000	1.0
MP-6	0.50	6	1.013	-0.4	0.999	0.378	1.0
	0.20	5	1.005	-0.3	0.999	0.632	0.5
	0.10	4	0.999	0.2	0.999	0.228	0.4
	0.05	3	0.995	0.1	0.999	0.231	0.6
MP-7	0.50	2	0.986	0.0	0.999	0.000	1.2
	0.20	2	0.958	0.0	0.999	0.000	3.5
	0.10	2	0.970	0.0	0.999	0.000	2.5
	0.05	2	0.976	0.0	0.999	0.000	2.0

Table II-3-11-(5) Correlation between concentrations of equivalent solution and SO_2 analyzer indication at calibration (3rd calibration, prior calibration)

SO_2 analyzer	Range (ppm)	Parameter	Regression equation $y = ax + b$		Correlation coefficient	Deviation from equation	Deviation from y=x
		n	a	b	r	σE	(%)
MP-1	0.50	6	0.999	-1.0	0.999	0.623	0.4
	0.20	5	0.993	-0.4	0.999	0.689	1.0
	0.10	4	0.988	0.2	0.999	0.159	1.0
	0.05	3	1.000	0.1	0.999	0.115	0.4
MP-2	0.50	6	1.004	-0.2	0.999	0.781	0.4
	0.20	5	0.999	-0.3	0.999	0.445	0.5
	0.10	4	1.004	0.2	0.999	0.171	0.5
	0.05	3	1.000	0.1	0.999	0.115	0.4
MP-3	0.50	6	1.000	-0.5	0.999	0.836	0.4
	0.20	5	1.001	-0.6	0.999	0.651	0.75
	0.10	4	1.000	0.0	1.000	0.000	0
	0.05	3	1.000	-0.1	0.999	0.116	0.4
MP-4	0.50	6	0.993	-0.1	0.999	0.635	0.6
	0.20	5	0.999	-0.1	0.999	0.440	0.5
	0.10	4	0.998	0.2	0.999	0.228	0.5
	0.05	3	0.983	0.3	0.999	0.500	1.4
MP-5	0.50	6	0.995	0.8	0.999	1.255	0.4
	0.20	5	0.999	-0.1	0.999	0.440	0.5
	0.10	4	1.000	0.0	1.000	0.000	0
	0.05	3	1.000	0.0	1.000	0.000	0
MP-6	0.50	6	1.013	-0.4	0.999	0.378	1.0
	0.20	5	1.005	-0.3	0.999	0.633	0.5
	0.10	4	0.999	0.2	0.999	0.228	0.4
	0.05	3	0.995	0.1	0.999	0.231	0.6
MP-7	0.50	6	0.998	-0.4	0.999	1.723	0.8
	0.20	5	0.999	-0.1	0.999	0.440	0.5
	0.10	4	1.000	0.0	1.000	0.000	0
	0.05	3	1.000	0.0	1.000	0.000	0

Table II-3-11-(6) Correlation between concentrations of equivalent solution and SO_2 analyzer indication at calibration (4th calibration, post calibration)

SO_2 analyzer	Range (ppm)	Parameter	Regression equation $y = ax + b$		Correlation coefficient	Deviation from equation	Deviation from y=x
		n	a	b	r	σ E	(%)
MP-1	0.50	2	0.981	0.0	0.999	0.000	1.6
	0.20	2	0.958	0.0	0.999	0.000	3.5
	0.10	2	0.964	0.0	0.999	0.000	3.0
	0.05	2	0.976	0.0	0.999	0.000	2.0
MP-2	0.50	6	0.993	0.1	0.999	0.245	0.6
	0.20	5	0.994	0.2	0.999	0.209	0.5
	0.10	4	1.013	0.1	0.999	0.257	1.0
	0.05	3	1.005	0.1	0.999	0.115	0.6
MP-3	0.50	6	0.997	-0.8	0.999	0.576	0.4
	0.20	5	1.001	-0.6	0.999	0.621	0.5
	0.10	2	0.988	0.0	0.999	0.000	1.0
	0.05	2	1.020	0.0	0.999	0.000	1.6
MP-4	0.50	6	1.000	-0.5	0.999	0.836	0.4
	0.20	2	0.982	0.0	0.999	0.000	1.5
	0.10	4	0.997	0.3	0.999	0.322	0.7
	0.05	3	0.988	0.2	0.999	0.318	1.0
MP-5	0.50	6	0.993	0.1	0.999	0.245	0.6
	0.20	5	0.994	0.3	0.999	0.333	0.5
	0.10	4	0.999	0.5	0.999	0.618	1.3
	0.05	3	0.991	0.2	0.999	0.404	1.0
MP-6	0.50	2	1.026	0.0	0.999	0.000	2.2
	0.20	5	1.003	-0.9	0.999	0.641	0.75
	0.10	4	0.997	-0.5	0.999	0.463	1.0
	0.05	2	0.988	0.0	0.999	0.000	1.0
MP-7	0.50	2	1.019	0.0	0.999	0.000	1.6
	0.20	5	0.998	2.4	0.999	1.636	2.0
	0.10	4	0.988	1.3	0.999	1.248	2.0
	0.05	3	0.993	0.3	0.999	0.491	1.4

Table II-3-11-(7) Correlation between concentrations of equivalent solution and SO_2 analyzer indication at calibration (4th calibration, prior calibration)

SO_2 analyzer	Range (ppm)	Parameter	Regression equation $y = ax + b$		Correlation coefficient	Deviation from equation	Deviation from y=x
		n	a	b	r	σE	(%)
MP-1	0.50	6	1.003	-1.8	0.999	1.162	0.6
	0.20	5	1.002	-0.8	0.999	0.524	0.5
	0.10	4	1.003	-0.5	0.999	0.463	1.0
	0.05	3	1.000	-0.2	0.999	0.346	1.2
MP-2	0.50	6	0.993	0.1	0.999	0.245	0.6
	0.20	5	0.994	0.2	0.999	0.209	0.5
	0.10	4	1.013	0.1	0.999	0.258	1.0
	0.05	3	1.005	0.1	0.999	0.116	0.6
MP-3	0.50	6	0.997	-0.8	0.999	0.576	0.4
	0.20	5	1.007	-0.6	0.999	0.621	0.5
	0.10	4	1.001	0.10	0.999	0.249	0.5
	0.05	3	1.000	-0.2	0.999	0.289	1.0
MP-4	0.50	6	1.000	-0.5	0.999	0.836	0.4
	0.20	5	0.999	-0.1	0.999	0.468	0.5
	0.10	4	0.997	0.3	0.999	0.322	0.7
	0.05	3	0.988	0.2	0.999	0.318	1.0
MP-5	0.50	6	0.993	0.1	0.999	0.245	0.6
	0.20	5	0.994	0.3	0.999	0.333	0.5
	0.10	4	0.999	0.5	0.999	0.618	1.3
	0.05	3	0.991	0.2	0.999	0.404	1.0
MP-6	0.50	6	1.004	-1.9	0.999	1.096	0.6
	0.20	5	1.003	-0.9	0.999	0.641	0.75
	0.10	4	0.997	-0.5	0.999	0.463	1.0
	0.05	3	1.000	-0.2	0.999	0.289	1.0
MP-7	0.50	6	1.001	2.8	0.999	3.969	2.0
	0.20	5	0.998	2.4	0.999	1.636	2.0
	0.10	4	0.988	1.3	0.999	1.248	2.0
	0.05	3	0.993	0.3	0.999	0.491	1.4

Table II-3-11-(8) Correlation between concentrations of equivalent solution and SO_2 analyzer indication at calibration (5th calibration, post calibration)

SO_2 analyzer	Range (ppm)	Parameter	Regression equation $y = ax + b$		Correlation coefficient	Deviation from equation	Deviation from y=x
		n	a	b	r	σE	(%)
MP-1	0.50	6	1.006	-1.9	0.999	1.937	0.8
	0.20	5	1.001	-0.7	0.999	0.836	1.0
	0.10	2	0.988	0.0	0.999	0.000	1.0
	0.05	3	0.993	-0.1	0.999	0.087	0.6
MP-2	0.50	2	0.976	0.0	0.999	0.000	2.0
	0.20	2	0.970	0.0	0.999	0.000	2.5
	0.10	2	0.967	0.0	0.999	0.000	2.8
	0.05	2	0.986	0.0	0.999	0.000	1.2
MP-3	0.50	6	0.993	-1.3	0.999	1.817	1.0
	0.20	2	0.982	0.0	0.999	0.000	1.5
	0.10	2	0.976	0.0	0.999	0.000	2.0
	0.05	3	1.000	-0.1	0.999	0.173	0.6
MP-4	0.50	6	0.994	-0.4	0.999	0.660	0.6
	0.20	5	0.999	-0.1	0.999	0.220	0.25
	0.10	2	0.980	0.0	0.999	0.000	1.7
	0.05	2	0.981	0.0	0.999	0.000	1.6
MP-5	0.50	2	0.988	0.0	0.999	0.000	1.0
	0.20	2	0.988	0.0	0.999	0.000	1.0
	0.10	4	0.988	0.2	0.999	0.330	1.0
	0.05	3	1.000	0.0	1.000	0.000	0.0
MP-6	0.50	6	1.005	-2.9	0.999	1.811	1.0
	0.20	5	1.000	-1.0	0.999	1.225	1.5
	0.10	2	0.969	0.0	0.999	0.000	2.6
	0.05	2	0.976	0.0	0.999	0.000	2.0
MP-7	0.50	2	0.974	0.0	0.999	0.000	2.2
	0.20	2	0.976	0.0	0.999	0.000	2.0
	0.10	2	0.952	0.0	0.999	0.000	4.0
	0.05	2	0.948	0.0	0.999	0.000	4.4

In order to investigate the drift of SO_2 analyzer (deviation of indicating values of SO_2 analyzer during about 3 months between prior and post calibration), the equivalent solution of 420 ppb (full scale 500 ppb), 168 ppb (full scale 200 ppb), 84 ppb (100 ppb), and 42 ppb (50 ppb) are introduced into analyzer, and the ratio of indicating values $\left(\frac{\text{post calibration}}{\text{prior calibration}}\right)$ and drift $\left(\frac{\text{post cal. value - prior cal.}}{\text{full scale}} \times 100\right)$ are calculated as shown in Table II-2-12-(1) to -(4).

From the above, the large difference between concentrations of equivalent solution and indicating values of analyzer is not found and the drift is confirmed to be very small.

Table II-3-12-(1) Drift of SO_2 analyzer (1st & 2nd calibration)

SO_2 analyzer	Range (ppm)	Post calibration value / Prior calibration value	Drift (%)
MP-1	0.50	-	-
	0.20	1.000	0.0
	0.10	0.996	-0.3
	0.05	1.000	0.0
MP-2	0.50	-	-
	0.20	0.976	-2.0
	0.10	0.952	-4.0
	0.05	0.952	-4.0
MP-3	0.50	-	-
	0.20	1.000	0.0
	0.10	1.000	0.0
	0.05	0.976	-2.0
MP-4	0.50	1.012	1.0
	0.20	1.006	0.5
	0.10	1.012	1.0
	0.05	1.002	0.2
MP-5	0.50	-	-
	0.20	1.000	0.0
	0.10	1.006	0.5
	0.05	1.007	0.6
MP-6	0.50	-	-
	0.20	1.048	4.0
	0.10	1.036	3.0
	0.05	1.048	4.0
MP-7	0.50	-	-
	0.20	1.006	0.5
	0.10	0.994	-0.5
	0.05	0.995	-0.4

Table II-3-12-(2) Drift of SO_2 analyzer (2nd & 3rd calibration)

SO_2 analyzer	Range (ppm)	Post calibration value / Prior calibration value	Drift (%)
MP-1	0.50	0.998	-0.2
	0.20	0.994	-0.5
	0.10	0.988	-1.0
	0.05	1.000	0.0
MP-2	0.50	1.005	0.4
	0.20	1.012	1.0
	0.10	1.005	0.4
	0.05	1.043	3.6
MP-3	0.50	0.983	-1.4
	0.20	0.970	-2.5
	0.10	0.958	-3.5
	0.05	0.971	-2.4
MP-4	0.50	0.993	-0.6
	0.20	0.976	-2.0
	0.10	0.976	-2.0
	0.05	0.983	-1.4
MP-5	0.50	0.995	-0.4
	0.20	1.000	0.0
	0.10	0.976	-2.0
	0.05	0.988	-1.0
MP-6	0.50	1.012	1.0
	0.20	1.006	0.5
	0.10	1.000	0.0
	0.05	0.995	-0.4
MP-7	0.50	0.986	-1.2
	0.20	0.958	-3.5
	0.10	0.970	-2.5
	0.05	0.976	-2.0

Table II-3-12-(3) Drift of SO_2 analyzer (3rd & 4th calibration)

SO_2 analyzer	Range (ppm)	$\frac{\text{Post calibration value}}{\text{Prior calibration value}}$	Drift (%)
MP-1	0.50	0.983	-1.4
	0.20	0.964	-3.0
	0.10	0.976	-2.0
	0.05	0.976	-2.0
MP-2	0.50	0.988	-1.0
	0.20	0.994	-0.5
	0.10	1.007	0.6
	0.05	1.005	0.4
MP-3	0.50	0.995	-0.4
	0.20	1.006	0.5
	0.10	0.988	-1.0
	0.05	1.019	1.6
MP-4	0.50	1.007	0.6
	0.20	0.982	-1.5
	0.10	1.000	0.0
	0.05	1.005	0.4
MP-5	0.50	0.998	-0.2
	0.20	0.994	-0.5
	0.10	1.000	0.0
	0.05	0.990	-0.8
MP-6	0.50	1.014	1.2
	0.20	0.994	-0.5
	0.10	0.994	-0.5
	0.05	0.993	-0.6
MP-7	0.50	1.019	1.6
	0.20	1.006	0.5
	0.10	0.994	-0.5
	0.05	0.993	-0.6

Table II-3-12-(4) Drift of SO_2 analyzer (4th & 5th calibration)

SO_2 analyzer	Range (ppm)	Post calibration value / Prior calibration value	Drift (%)
MP-1	0.50	1.005	0.4
	0.20	1.000	0.0
	0.10	0.988	-1.0
	0.05	0.993	-0.6
MP-2	0.50	0.983	-1.4
	0.20	0.976	-2.0
	0.10	0.955	-3.8
	0.05	0.981	-1.6
MP-3	0.50	0.998	-0.2
	0.20	0.976	-2.0
	0.10	0.976	-2.0
	0.05	1.000	0.0
MP-4	0.50	0.993	-0.6
	0.20	1.000	0.0
	0.10	0.980	-1.7
	0.05	0.993	-0.6
MP-5	0.50	0.995	-0.4
	0.20	0.994	-0.5
	0.10	0.988	-1.0
	0.05	1.010	0.8
MP-6	0.50	1.000	0.0
	0.20	1.000	0.0
	0.10	0.975	-2.1
	0.05	0.976	-2.0
MP-7	0.50	0.974	-2.2
	0.20	0.970	-2.5
	0.10	0.958	-3.5
	0.05	0.954	-3.8

II-3-4-2 SO_2 ambient concentration

(1) Reading of recording chart of SO_2 analyzer

To maintain the high accuracy of measurement by analyzer, five ranges (0-0.05, 0-0.2, 0-0.5, 0-1.0 ppm) are automatically switched within the analyzer. As shown in Fig. II-3-16, by setting the range selector to AUTO, measurement starts with 0.05 ppm range, which is automatically switched to 0.1 ppm range when the full scale of the initial range has been reached. Thus 0.1 ppm range is automatically switched to 0.2 ppm range when 0.1 ppm scale has been reached. In the same way, the range is successively switched to the larger one. The starting range (0-0.05 ppm) is reset at the end of a measurement cycle.

Fig. II-3-16 shows a sample of chart reading. The top of saw-teeth indicates SO_2 concentration of the cycle.

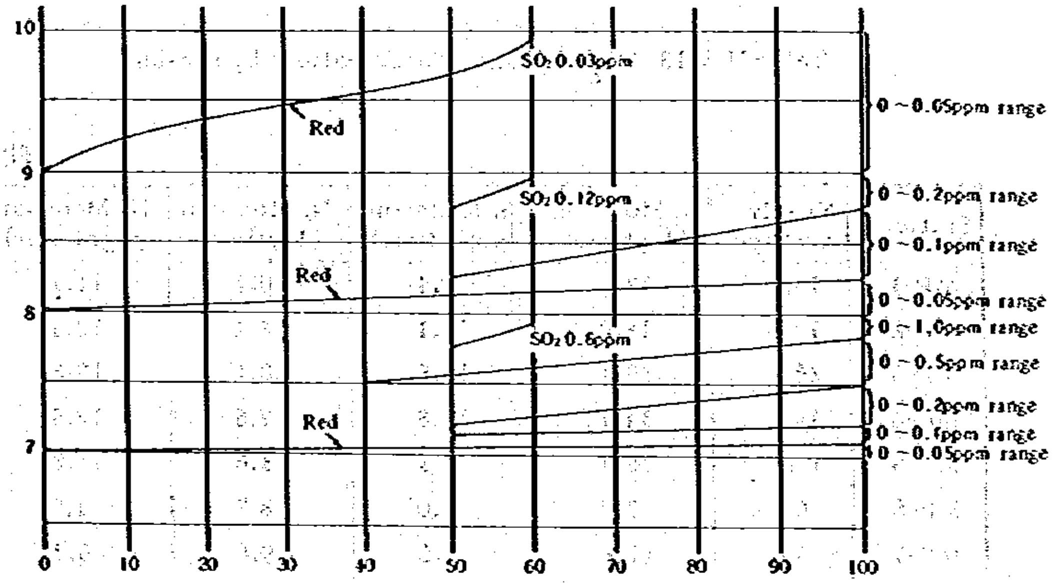


Fig. II-3-16 A sample of chart recording

(2) Results of measurement

The effective measurement time of MP-1 to MP-7 are mentioned hereunder and these number of hours are exceeding the measurement time of effective stations in Japan.

Station	Effective measurement hour	Percentage
MP-1	8,145	93.0%
MP-2	8,329	95.1%
MP-3	8,411	96.0%
MP-4	7,526	85.9%
MP-5	8,137	92.9%
MP-6	8,404	95.9%
MP-7	8,151	93.0%

The raw data of one hour average values of SO_2 concentration obtained at 7 monitoring stations are compiled in ANNEX. Yearly average SO_2 concentrations classified by season and day & night are shown in Table II-3-13. The order of yearly average concentration from high to low are MP-3, MP-4, MP-2, MP-1, MP-7 and MP-6.

The other analyzed results of SO_2 concentration, such as monthly and daily deviation patterns will be described in PART IV.

Table II-3-13 SO_2 average concentrations by season

(ppb)

Station	Yearly average	S. Monsoon (daytime)	S. Monsoon (nighttime)	N. Monsoon (daytime)	N. Monsoon (nighttime)
MP-1	14.2	17.5	9.4	20.7	11.7
MP-2	14.6	18.0	11.1	18.4	12.1
MP-3	26.2	39.3	18.5	28.4	19.8
MP-4	19.4	34.1	12.8	17.8	12.9
MP-5	17.6	26.9	10.3	23.6	11.8
MP-6	6.7	7.7	6.0	8.7	4.9
MP-7	8.4	11.3	7.6	9.6	5.2

Remarks:

S. Monsoon	April - October
N. Monsoon	November - March
Daytime	7:00 to 17.59
Nighttime	18:00 to 6.59

Table II-3-14 An example of SO_2 ambient concentration (hourly average) of monitoring stations

SINGAPORE SO2 ST. 1 .99.7%
1981. 8.

DAY	1H	2H	3H	4H	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H	21H	22H	23H	24H	MEAN	MAX	MIN
1	7	8	7	8	6	5	7	10	8	7	9	8	8	7	7	8	8	7	8	7	6	6	7	6	7	10	5
2	7	7	8	7	5	5	5	9	9	11	30	59	59	26	13	10	9	10	11	8	7	6	6	7	14	59	5
3	8	9	7	6	5	4	4	7	8	10	11	9	8	9	9	12	12	11	10	14	18	9	7	6	9	18	4
4	7	6	5	6	5	6	6	7	7	7	8	8	9	10	10		10	11	9	8	7	10	10	9	8	11	5
5	11	9	7	7	5	7	7	10	27	13	10	12	9	9	10	10	12	13	17	20	15	11	18	9	12	27	5
6	8	7	6	6	8	8	7	8	10	10	11	11	13	13	12	15	15	12	9	9	10	9	7	7	10	15	6
7	8	9	7	6	5	5	6	7	46	50	11	12	11	14	15	13	12	11	9	7	9	10	9	7	12	50	5
8	6	7	5	5	5	5	7	10	40	12	10	10	10	10	10	11	10	10	9	8	9	9	7	6	10	40	5
9	6	5	6	6	6	6	6	9	8	8	10	10	11	11	12	12	11	10	9	8	8	7	6	6	8	12	5
10	7	7	6	7	6	5	6	7	10	9	8	8	9	10	12	11	13	10	10	9	10	8	7	7	8	13	5
11	7	8	5	4	4	6	7	9	10	26	24	10	11	11	11	12	13	10	9	7	6	6	6	6	10	26	4
12	6	5	7	6	5	5	5	7	30	51	12	11	10	10	11	11	11	10	8	9	7	7	7	8	11	51	5
13	6	6	5	5	5	4	4	8	15	11	10	10	10	10	10	11	12	11	9	8	8	7	6	6	8	15	4
14	6	6	5	5	5	5	5	10	30	26	13	11	11	12	13	15	13	12	10	8	7	8	7	7	10	30	5
15	6	6	5	5	6	7	9	12	13	11	10	11	11	11	12	12	12	12	10	8	7	7	7	6	9	13	5
16	6	5	5	5	5	5	5	5	7	8	6	10	12	12	13	12	11	11	10	9	9	10	8	7	8	13	5
17	6	6	5	5	6	8	13	23	16	26	35	18	12	37	30	34	17	12	12	8	8	6	7	7	15	37	5
18	6	6	7	6	6	6	6	22	7	7	14		9	9	9	10	10	9	7	6	6	7	8	7	8	22	6
19	7	7	5	4	4	4	6	7	9	29	11	10	9	9	8	8	9	9	8	7	8	7	5	5	8	29	4
20	7	5	4	4	4	5	6	12	22	12	32	14	9	12	10	9	9	11	9	9	8	8	12	11	10	32	4
21	9	9	15	11	8	6	6	9	11	12	11	11	10	9	16	14	14	21	15	9	8	7	6	6	11	21	6
22	6	6	6	6	5	4	4	5	40	51	14	12	16	19	18	16	16	12	11	10	12	10	11	11	13	51	4
23	11	10	12	8	7	6	6	11	12	9	9	9	9	8	10	12	10	9	8	8	7	6	7	6	9	12	6
24	6	5	4	4	4	4	5	11	22	20	39	14	11	11	9	10	13	21	9	9	18	12	7	9	12	39	4
25	12	8	12	19	14	7	5	6	7	12	9	13	16	11	10	11	9	9	9	9	7	7	6	7	10	19	5
26	8	8	7	5	5	5	5	14	31	35	13	11	9	8	49	37	23	10	9	9	9	7	7	10	14	49	5
27	11	8	6	5	5	4	8	10	12	49	15	18	11	11	25	10	14	12	10	9	11	11	11	6	12	49	4
28	8	12	10	9	7	6	7	14	24	39	15	14	15	23	14	11	29	14	10	9	9	8	7	6	13	39	6
29	7	8	7	6	5	5	5	8	22	25	21	18	20	38	12	24	17	17	17	9	12	8	8	6	14	38	5
30	8	9	6	6	6	5	5	13	10	9	9	10	10	11	10	10	9	9	8	9	7	7	7	6	8	13	5
31	9	7	6	6	5	6	5	7	12	10	13	22	15	13	12	16	20	11	9	7	7	8	7	7	10	22	5
MONTHLY																									10	59	4

UNIT : PPB

CHAPTER 4 MEASUREMENT OF WIND DIRECTION AND WIND VELOCITY

For environmental assessment on air quality, the meteorological conditions of the survey area are the important factors to obtain the tendency of smoke diffusion. Among meteorological factors, the wind status of the survey area is the necessary factor to investigate the relation with the ambient concentrations of the pollutants.

In this study, the monitoring of wind direction and velocity have been carried out at the same 7 monitoring stations by the automatic and continuous instruments. The daily check and the maintenance work of every 3 months have been conducted for one year.

II-4-1 Measuring Methods of Wind Direction and Velocity

The instruments to measure wind direction and velocity have been developed with a long history, as the measurement of wind direction and velocity is the most fundamental one among meteorological factors. At present, the following 3 types of instruments are most commonly used.

(1) combination of cup-type and arrow-type anemometer
(2) propeller type anemometer
(3) super sonic anemometer

Among above 3 types of anemometer, (2) is commonly used for measurements in the field of pollution, which is sometimes called as windmill type anemometer.

The wind velocity is measured by propeller which is facing directly with the wind and connected with DC generator. The wind direction is measured by the sensor itself which is designed as arrow type and is connected with transmitter.

Super sonic anemometer has just recently developed and its measuring principle is to detect difference of the transmission speed of super sonic in the atmosphere at windward and leeward. Because of the fact that all the parts of the instruments are not mobile, it has the following advantages;

(a) wind velocity of 0 m/s is measurable
(b) responding speed is faster
(c) fitted to measure fluctuation of wind direction and velocity, as well as atmospheric turbulence

The anemometer of above (1) is not so used recently.

II-4-2 Anemometer Used in This Study

The anemometer used in this study is 4-blade propeller type anemometer which are widely used by the air pollution monitoring stations of Japan. The manufacturers of the anemometer of this type are 3 companies in Japan, but from the past records and contribution, KOSHIN DENKI KOGYO Co., Ltd. has been selected and adopted. The specifications are shown in Table II-4-1 and its outside view is shown in Pictures II-4-1-(1) to -(3).

The instrument is composed by sensor, averaging device and recorder, as shown in Picture II-4-1.

The wind velocity is measured by detecting difference of the electric voltage generated by generator connected to propeller as shown in Fig. II-4-1.

The wind direction is measured by detecting the rotating angle of the sensor which is converted to electrical voltage. Two potentiometers installed are designed to shift automatically to the same direction of the central part when the indicator is reached to the end of the span.

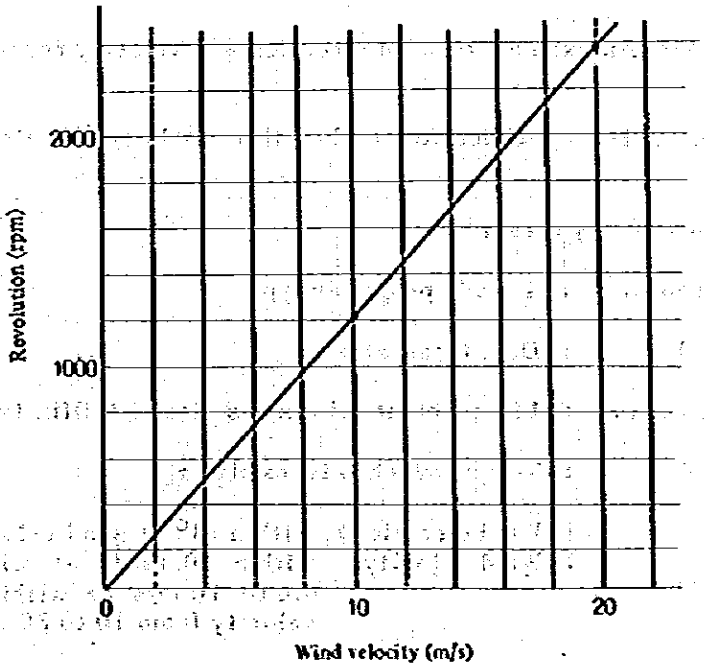


Fig. II-4-1 Propeller characteristics (wind velocity v.s. R.P.M.)

As shown in Fig. II-4-2, the recorder indicates instantaneous or average (10 minutes) values of wind direction and velocity by the switch of averaging device. The reading and analysis of instantaneous values are troublesome and so the average values are commonly recorded.

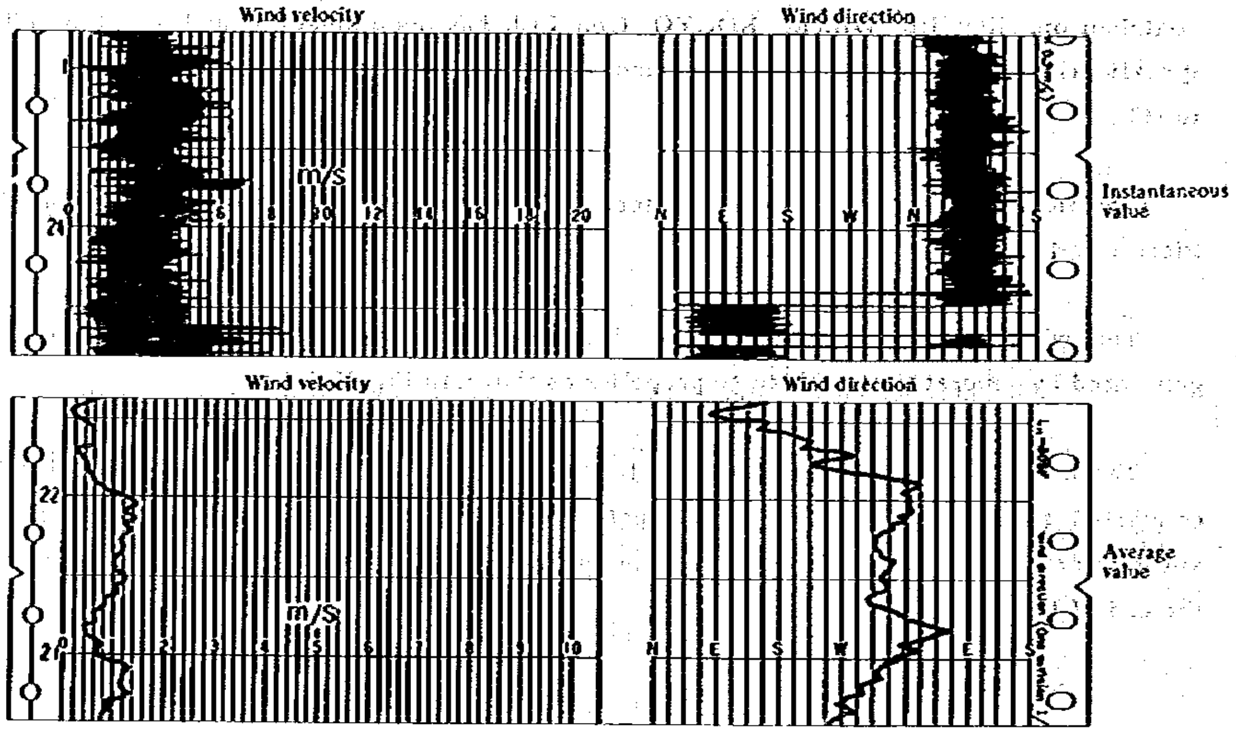


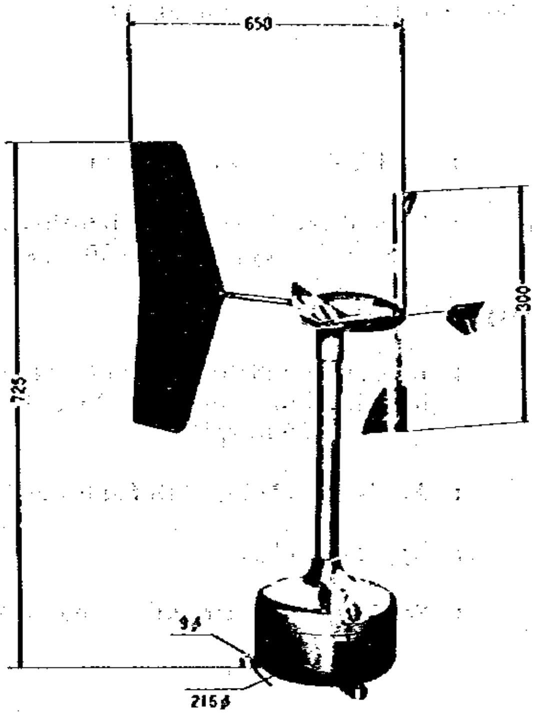
Fig. II-4-2 An example of wind direction and velocity recording

Table II-4-1 Specifications of low-threshold anemometer

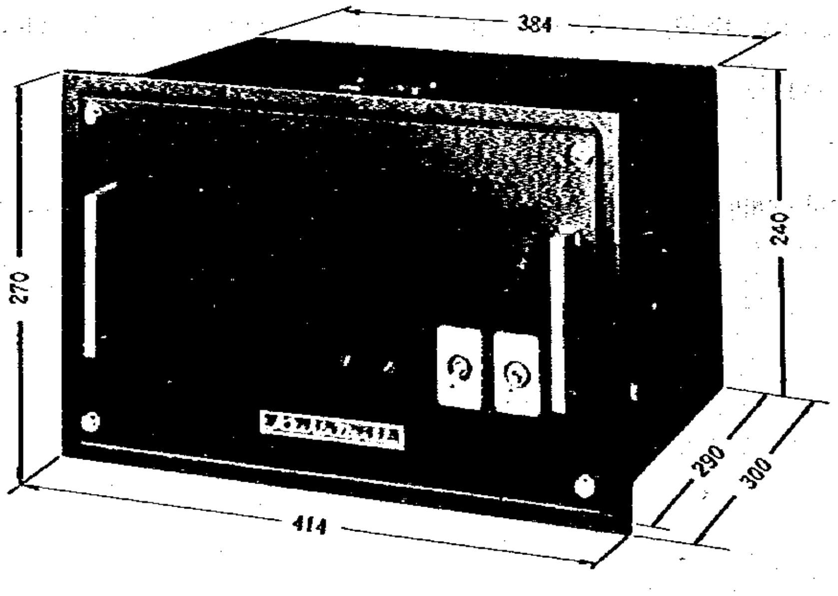
Wind direction and velocity sensor	
Wind velocity sensor	: 4-blade propeller type
Electrical signal	: D.C. Generator
Wind direction sensor	: Light weight reinforced plastic tailfin type
Electrical signal	: Torque synchro transmitter
Accuracy	: Wind direction; within ±3° at wind velocity 0.4 m/s : Wind velocity; within ±0.3 m/s at wind velocity from 0.4 to 10 m/s or within ±0.3% at wind velocity from 10 to 20 m/s
Maximum wind velocity	: 60 m/s
Cable for remote transmission	: Up to 1,000 m, 0.75 mm^2, 8-cond. cable, between sensor/transmitter and recorder or averaging device
Weight	: Approx. 5 kg.

Table II-4-1 Specifications of low-threshold anemometer (Cont'd)

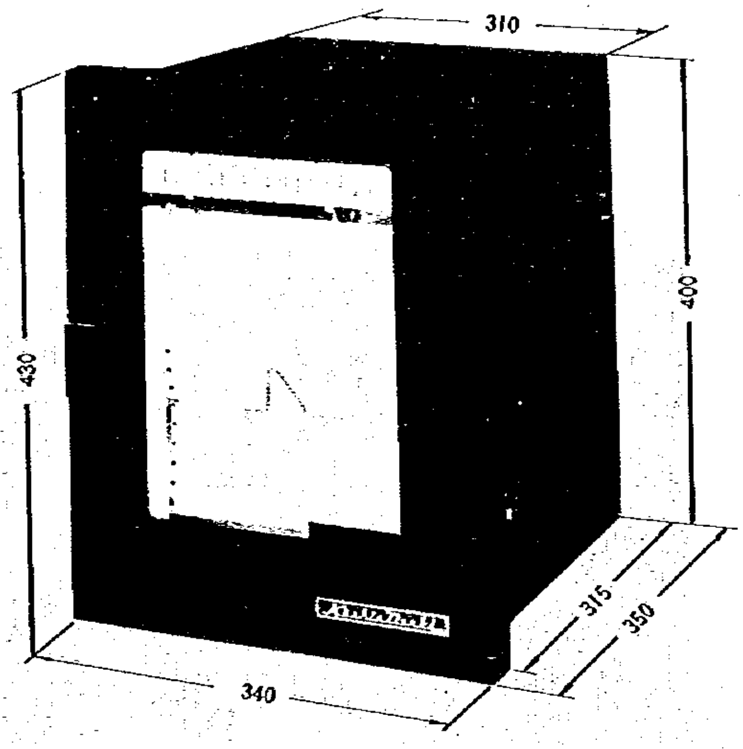
Recorder	
Type	Self-balancing, 2-pen system
Measurement range	Wind direction; All azimuths, with 540°/360° shifting Wind velocity; 0.4 to 20 m/s
Chart feeding velocity	30 mm/H
Chart	Effective width-180 mm (speed-100 mm, direction-70 mm) length-23 m (corresponding to 1 month's recording at speed of 30 mm/H)
Power supply	AC 100 V ±10%, both for 50 and 60 Hz
Weight	Approx. 28 kg.
External casing	For both flush mounting and desk-top mounting
Averaging device	
Electrical signal for recording	Manual switch between average and instantaneous values
Output signal	Average direction (0-540°) 0-1 V impedance 100 Average velocity (0-10 m/s) 0-1 V impedance 100
Averaging method	10 minutes sequential average by electrical integration
Power supply	AC 100 V ±10%, both for 50 and 60 Hz
Weight	Approx. 20 kg.
External casing	For both flush mounting and desk-top mounting



Picture II-4-1-(1) Outside view of anemometer (sensor)



Picture II-4-1-(2) Outside view of anemometer (averaging device)



Picture II-4-1-(3) Outside view of anemometer (recorder)

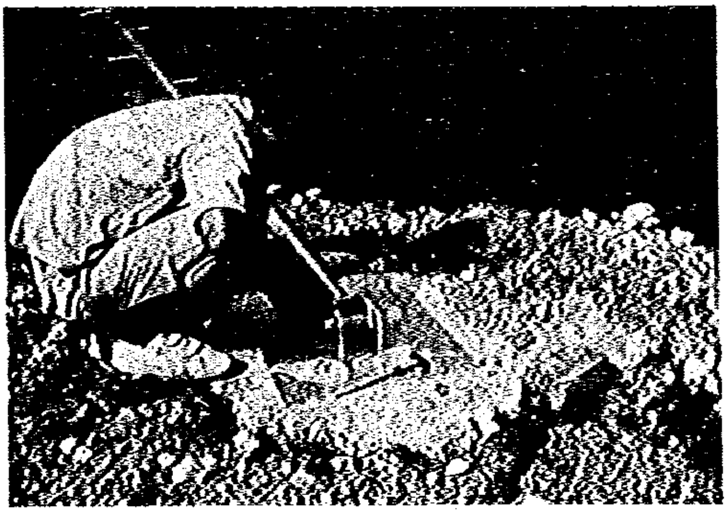
II-4-3 Measurement

The anemometers used in this study have been inspected by the Meteorological Agency, Japanese Government, prior to the transportation to Singapore and it is effective for 5 years. Therefore, the instruments are not necessary to be calibrated as long as they are properly installed. The processes of preparation for measurement are described.

II-4-3-1 Erection of pole

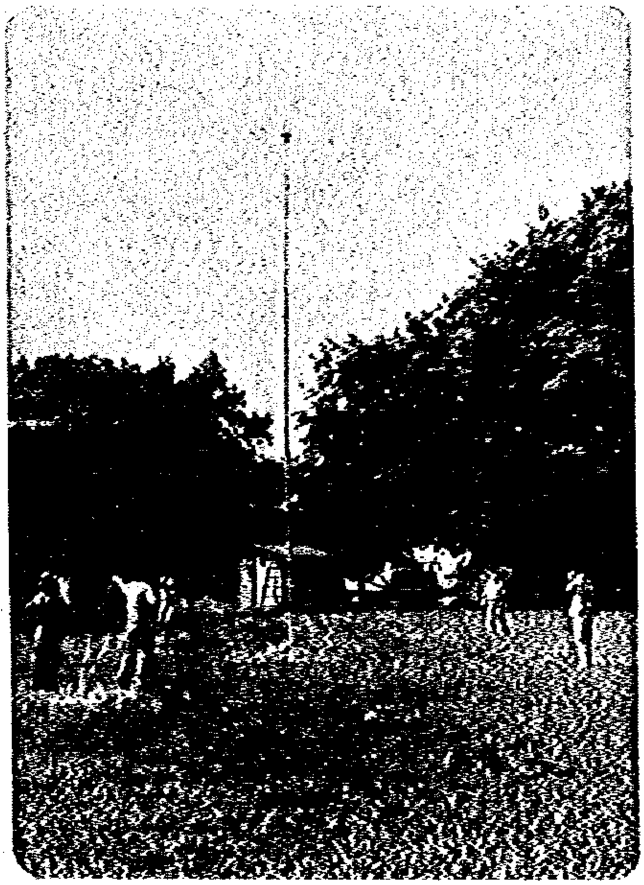
For the correct measurement of wind direction and velocity, the obstacles disturbing wind should not be existed in the immediate surrounding area. The pole of 10 m high is generally erected and the sensor of the anemometer is installed on the top of the pole. Prior to erection of the pole, consideration should be given to the impact of trees and buildings.

For erection of pole, the concrete foundations for pole and the stays are prepared as shown in Picture II-4-3, and the pole is erected. The pole erected on the concrete foundation is supported by the stays which should be firmly connected to the concrete foundations prepared for the stay as shown in Picture II-4-3. By adjusting the length of stays, the pole should be set in the vertical position, as shown in Picture II-4-4.



Picture II-4-2 Foundation for pole erection

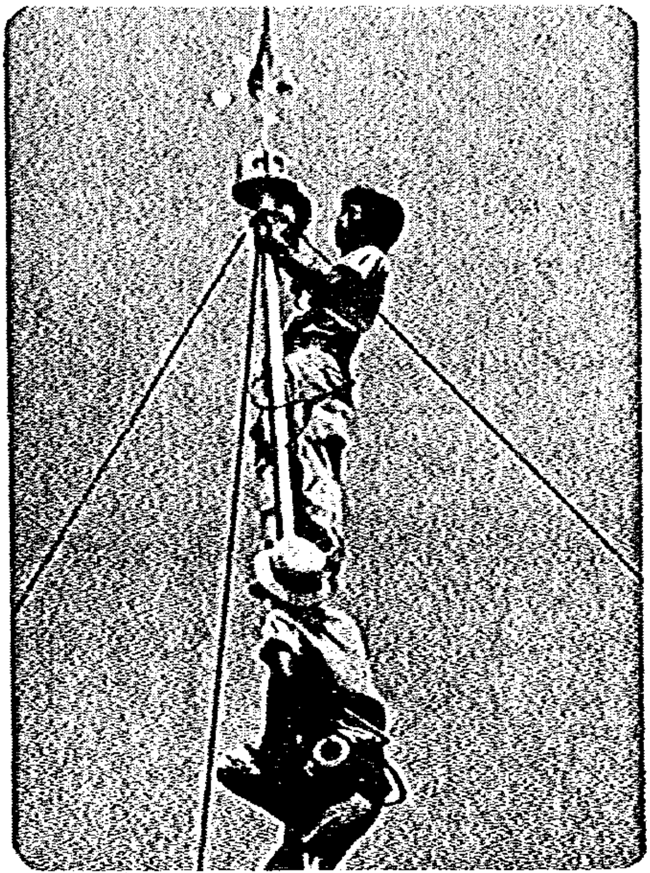
Picture II-4-3 Erection of pole for anemometer



Picture II-4-4 Settlement of pole for anemometer

II-4-3-2 Installation of anemometer sensor

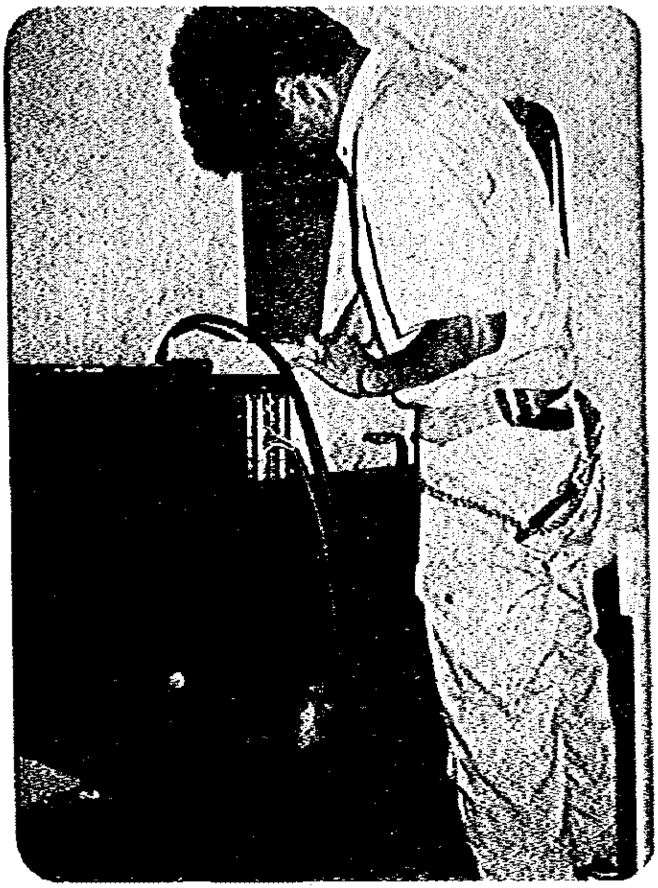
The sensor of the anemometer is installed on the top of pole as shown in Picture II-4-5, setting N mark of sensor to the north by using magnet, setting also S mark of sensor to the south, and confirming horizontal level by using a level. In case of Singapore, the difference between due north and magnet north is 10 minutes which is little worth of consideration.



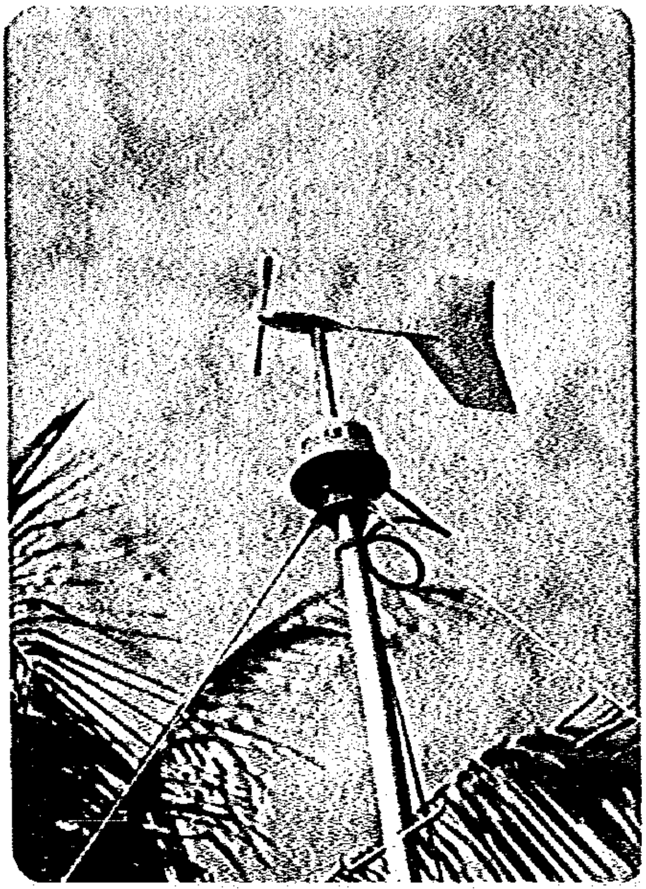
Picture II-4-5 Installation of anemometer sensor

II-4-3-3 Method of connections

The sensor and the recorder are connected by the cable in the order of sensor-arrestor-averaging device-recorder. The connected cable is firmly fixed to the pole by the belting materials and the cable extending on the ground is usually laid under the ground to avoid the troubles by traffic, as shown in Picture II-4-7 and Picture II-4-8.



Picture II-4-6 Connection of cable and recorder



Picture II-4-7 Fixation of cable

Picture II-4-8 Cable laid under ground

II-4-3-4 Loading of chart

Loading of the chart is performed by the following procedures.

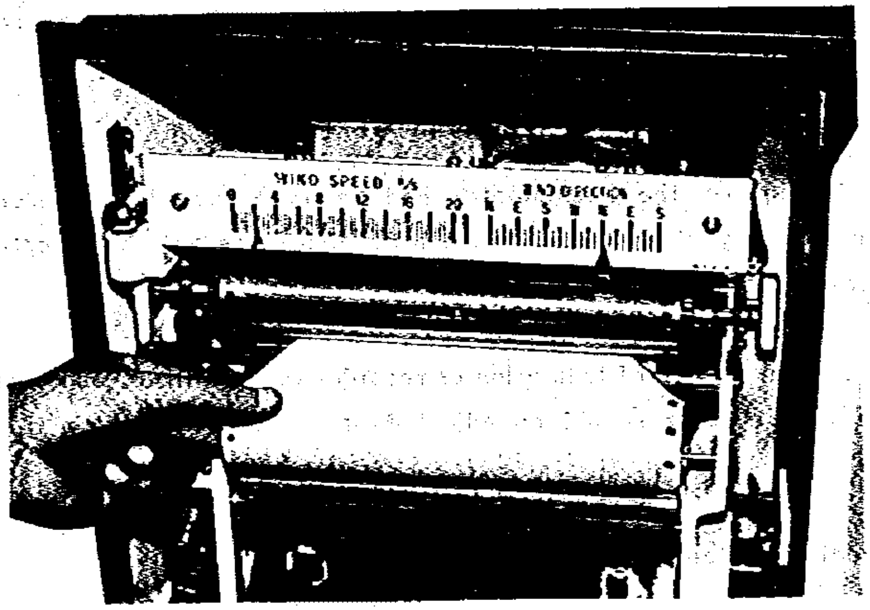
(1) Prepare the designated chart and ruffle it to avoid sticking.

(2) Pull the front plate beneath the sprocket to the operator, insert the chart into the chart holder in such a direction that the reverse surface faces to the operator when the recording pen is automatically lifted up from the sprocket.

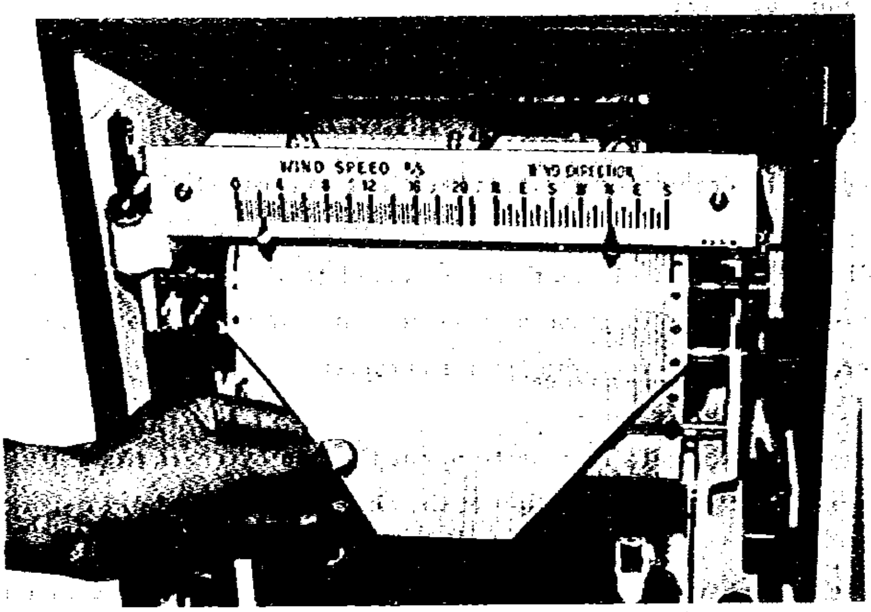
(3) In order to facilitate its insertion, cut the end of chart in an acute angle and as shown in Picture II-4-9-(1), insert the chart through the lower side of sprocket.

Guide the chart upward by turning the knob of sprocket and pull it to the operator carefully in order for the chart may not contact the pen tip, as shown in Picture II-4-9-(2).

(4) Push down the front plate inside the chart, pull it further out, fold its tip twice or thrice, and introduce it into the chart holder.



Picture II-4-9-(1) Loading of chart



Picture II-4-9-(2) Loading of chart

II-4-3-5 Supply of ink

The ink is supplied to the ink tank, about 50 to 60% of its capacity. The excess supply of the ink causes overflood onto the chart. The thicker ink due to evaporation causes choking and therefore such should be diluted by distilled water or alcohol.

II-4-3-6 Adjustment of instrument

The calibration of the anemometer had been conducted, as described, by The Meteorological Agency which had effective term of 5 years and so the calibration at the site is usually not conducted.

However, the deviation of indication of recorder to the sensor, and deviation of zero indication of the recorder should be adjusted at the site according to the following procedures.

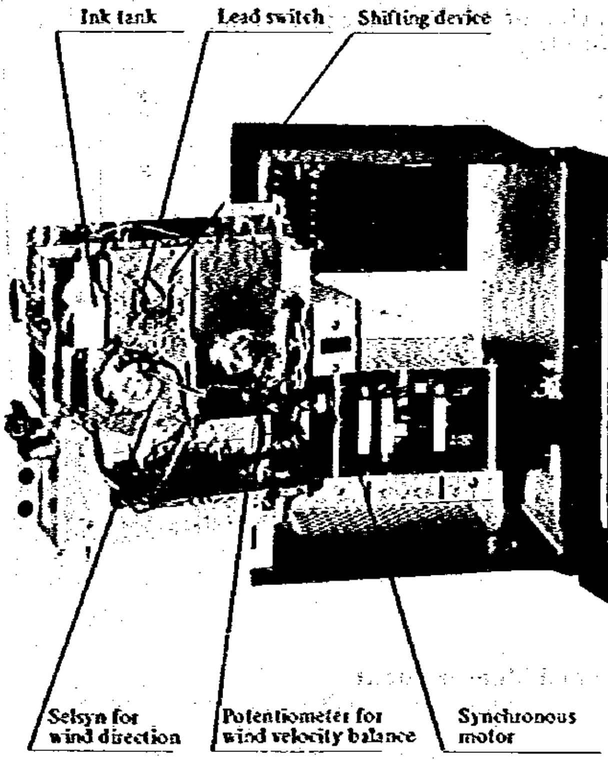
(1) Wind direction system

For adjustment of deviation in "N" direction between sensor and recorder, loosen, in the state of power switch being ON, 3 metal adaptors with which the control synchro is mounted on the rear surface of the internal device of the recorder and correct such deviation by turning control synchro.

(2) Wind velocity system

For adjustment of shifts from the zero point of the wind velocity recording device, loosen the metal adaptor with which the balancing potentiometer is mounted on the rear surface of the internal device and correct such shifts by turning the potentiometer.

After the above adjustment, the averaging device is switched to the position of averaging value, and measure more than 10 minutes to confirm the indicating values.



Picture II-4-10 Position of metal adapter for adjustment of wind direction and velocity of anemometer

II-4-3-7 Automatic measurement

Turn the function of selector of averaging device from INSTANTANEOUS to AVERAGE and set the recording pen to the present position on the chart. Then, the automatic and continuous measurement will be commenced.

II-4-3-8 Maintenance and Inspection

For the sound operation of anemometer and to secure the accuracy of measurement for a long term, the periodical maintenance and inspection are required as shown in Table II-4-2.

Table II-4-2 Items and frequency of maintenance and inspection for anemometer

Maintenance and Inspection		Frequency			
Item	Contents	Daily	Week	Month	3 M.
Pole	Inspection: confirmation of vertical erection and stretch of stay	x			
Sensor	Inspection: confirmation of rotation	x			
Recorder	Inspection: confirmation of chart advance, time deviation and ink shade	x			
	Replacement: chart replacement			x	
	Supply: ink supply		x		
Adjustment	Adjustment: adjustment of N of sensor and recorder				x
	adjustment of wind velocity zero				x
Power cable and its connection	Inspection: confirmation of loose and disconnection	x			

II-4-4 Results of Maintenance and Measurement

The measurement of surface wind direction and velocity has been conducted for one year, from July 15th 1981 to July 14th 1982, by automatic and continuous measuring instruments. During the above one year, the maintenance and inspection of instruments have been conducted, daily by JTC and 3 times adjustment by Japanese team. The results of maintenance and measurement are described.

II-4-4-1 Maintenance

(1) Daily inspection

According to the items and frequency described in Table II-4-2, the daily maintenance of anemometers installed in 7 monitoring stations has been conducted by JTC on the following items.

(a) confirmation of vertical erection of pole
(b) inspection of rotation status of the sensor
(c) confirmation of chart advance
(d) confirmation of time deviation of the recorder
(e) confirmation of ink shade and ink supply
(f) inspection of loose or disconnection of power cable

Besides the above, the chart has been replaced once per month by JTC according to the methods described in II-4-3-4.

(2) Adjustment of anemometer

For the sound operation and to secure the accuracy of measurement, the adjustment of anemometer has been conducted once every 3 months by the methods described in II-4-5-6. At adjustment, the anemometer has been inspected according to the form shown in Table II-4-3.

Table II-4-3 Maintenance and inspection form of anemometer

PROPELLER TYPE WIND VANE MAINTENANCE REPORT (Every 3 months)

Station : MP-

Maintenance Items	Result
Wind vane operating condition	Good No
Chart printing	Good No
Chart slip	Good No
Ink balance	3/4, 1/2, 1/4
Pole condition	Good No
Indicated voltage of A.V.R.	V
Remarks:	

Check of the wind direction	
Sensor	Recorder
N	
S	
Check of the wind velocity	
Sensor	Recorder
0 m/s	m/s
Remarks:	

Month/day /
Time
Weather
Surveyor

The results of adjustment of the anemometer installed in MP-1 to MP-7 are shown in Table II-4-4.

N and S of the sensor and recorder are well coincided in all the stations and recording of 0 m/s is also found satisfactory.

Table II-4-4 Results of adjustment of anemometer

Number of times	Sensor indication	Recorder indication						
		MP-1	MP-2	MP-3	MP-4	MP-5	MP-6	MP-7
1st	N S Wind velocity 0 m/s0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S
2nd	N S Wind velocity 0 m/s0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S
3rd	N S Wind velocity 0 m/s0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S
4th	N S Wind velocity 0 m/s0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S
5th	N S Wind velocity 0 m/s0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S 0 m/s	N S

II-4-4-2 Wind direction and velocity

(1) Reading of chart of anemometer

The weather observatory is usually reading the records of wind direction and velocity for 10 minutes before exact full hour. However, the air pollutants are measured as the value of one hour accumulated concentration and so the wind direction and velocity are also required to be monitored as the value of one hour average. In this study, the reading of the wind direction and velocity has been carried out by the following ways.

The wind direction and velocity are recorded as the running mean of 10 minutes values by averaging device, and so it is not necessary to obtain the one hour average value from instantaneous values. In this study, 6 values are recorded within one hour with the interval of Δt=10min. However, one hour average wind direction and velocity is not obtainable by simply averaging 6 values. For example, when N wind blows for 30 minutes and S wind blows for 30 minutes within one hour, average wind direction of this particular one hour will be W or E. Therefore, one hour average wind direction and velocity has been obtained by vector mean as under.

The wind direction and velocity recorded by the interval of Δt=10 min. are divided into N-S component and E-W component as shown in the equation (II-4-1).

$$\left.\begin{array}{ll} \text{N-S component} & V_{Ni} = V_i \times \cos\theta_i \\ \text{E-W component} & V_{Ei} = V_i \times \sin\theta_i \end{array}\right] \qquad \text{Equation II-4-1}$$

Where:

V: wind velocity (m/s)

θ: wind direction (degree)

i : 1 - 6

Averaging 6 V_{Ni} and V_{Ei} by equation II-4-2, one hour average V_N and V_E are calculated and applying to equation II-4-3, one hour average wind direction (θh) and velocity (Vh) are obtained by vector mean.

$$\left.\begin{array}{l} V_{N1\text{-}6} = \dfrac{V_{N1} + V_{N2} + V_{N3} + V_{N4} + V_{N5} + V_{N6}}{6} \\[2ex] V_{E1\text{-}6} = \dfrac{V_{E1} + V_{E2} + V_{E3} + V_{E4} + V_{E5} + V_{E6}}{6} \end{array}\right] \qquad \text{Equation II-4-2}$$

$$\left.\begin{array}{l} Vh = \sqrt{(V_{N1\text{-}6})^2 + (V_{E1\text{-}6})^2} \\[2ex] \theta_h = \tan^{-1}\left(\dfrac{V_{E1\text{-}6}}{V_{N1\text{-}6}}\right) \end{array}\right] \qquad \text{Equation II-4-3}$$

(2) Results of measurement

The effective measuring hours at 7 monitoring stations are shown as under and these numbers are exceeding the effective monitoring stations of Japan (yearly measuring hours = over 6,000 hours).

Station	Effective hours	Percentage
MP-1	8,568	97.8%
MP-2	8,316	94.9%
MP-3	7,332	83.7%
MP-4	8,628	98.5%
MP-5	8,340	95.2%
MP-6	8,544	97.5%
MP-7	8,484	96.8%

The raw data obtained at the respective 7 stations are collected and compiled into ANNEX. The average wind velocity classified by year, season and day & night is shown in Table II-4-5.

Table II-4-5 Average wind velocity

(unit = m/s)

Station	Yearly average	S. Monsoon daytime	S. Monsoon night-time	N. Monsoon daytime	N. Monsoon night-time
MP-1	0.9	1.2	0.5	1.3	0.7
MP-2	2.5	2.9	1.9	3.2	2.5
MP-3	0.7	0.6	0.4	1.1	0.7
MP-4	2.3	3.1	1.9	2.5	1.7
MP-5	0.7	0.7	0.3	1.1	0.7
MP-6	2.3	3.0	1.8	3.0	1.8
MP-7	1.4	1.4	0.8	2.3	1.5

From the monthly average wind velocity of each station, the tendency is found that during December to February, wind velocity is higher, and during March to May and September/October, wind is lower.

From the hourly average, the wind velocity of daytime is higher than the night time.

The wind direction of the respective stations has the tendency that during December to March, the wind of NNW to NE is dominant, during June to August, the wind of SSE to S is dominant and in the rest of months there are no dominant wind directions.

The detailed results of analysis of wind direction and velocity will be described in PART IV of this report.

Table II-4-6 An example of recording of one hour average wind direction and velocity

SINGAPORE　　ST. 1　　WIND DIRECTION
1981. 8.　　WIND SPEED(0.1M/S)　　100.0%

DAY	1H	2H	3H	4H	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H	21H	22H	23H	24H	MEAN	MAX	MIN
1	C 1	C 1	C 1	C 1	C 1	C 2	C 2	ESE 8	SE 19	S 8	SE 8	SSW 9	SW 15	W 12	SW 12	SSW 11	SSW 10	S 7	SSE 10	SE 10	C 2	ESE 5	C 3	C 2	7	19	1
2	C 1	C 2	C 1	C 1	C 1	C 2	C 2	ESE 6	C 4	WNW 7	C 1	C 3	W 9	WSW 12	SW 15	SSW 14	SW 11	SSW 8	SSE 9	SSE 12	C 4	SE 7	C 4	C 1	6	15	1
3	C 1	C 1	C 1	C 1	C 1	C 1	C 2	SE 8	SSE 11	SSE 12	S 11	SW 16	SW 20	SW 14	SW 13	S 14	S 10	S 8	SSE 11	SE 11	SE 7	SE 9	C 4	C 1	8	20	1
4	C 2	C 2	C 2	C 2	SE 5	SE 6	C 4	C 2	WSW 8	SW 12	WSW 15	SW 16	SW 15	SW 16	WSW 16	SSE 17	SSE 20	SSE 17	SE 10	SE 6	C 1	C 1	C 1	C 1	8	20	1
5	C 2	C 1	C 1	C 0	C 1	C 1	C 1	SE 7	SE 15	SSE 16	S 16	SSW 15	SSW 16	SW 14	SSW 15	SW 14	S 13	SSE 9	SSE 11	SSE 7	SE 7	C 4	C 3	C 4	8	16	0
6	C 1	ESE 6	C 1	C 4	SE 12	SE 12	SE 13	SE 15	SSE 18	SE 20	SSE 22	SSE 17	SE 21	SSE 22	SSE 22	SSE 14	SSE 23	SSE 21	SE 19	SE 16	SE 12	SE 9	C 1	C 1	13	23	1
7	C 1	C 1	C 1	C 1	SE 6	SE 8	SE 10	SE 12	SE 20	SE 23	SSE 22	SSE 27	SSE 24	SSE 25	SSE 22	SSE 26	SSE 25	SSE 19	SE 21	SE 16	SE 12	ESE 10	ESE 17	SE 15	15	27	1
8	SE 14	SE 14	SE 11	SE 11	C 3	SE 6	SE 5	SE 9	SE 18	SE 20	SE 24	SE 24	SE 28	SE 30	SE 32	SE 30	SE 30	SSE 17	WSW 15	SSE 15	SSE 11	SSE 9	S 8	SSW 8	16	32	3
9	SE 10	ESE 7	SE 9	SE 8	SE 8	C 2	C 1	ESE 5	SSE 18	SSE 16	S 8	SSW 13	SSW 12	SSW 13	SSE 20	SSE 20	SSE 19	SSE 14	SE 14	SE 13	SE 11	SE 12	SE 12	SE 8	11	20	1
10	C 4	C 2	C 1	C 3	SE 5	C 2	C 3	SE 9	SSE 5	SW 14	WSW 19	WSW 19	SW 20	SW 17	SSE 22	SSE 19	SSE 13	SSE 16	SE 11	SSE 8	SE 9	SE 5	C 2	C 2	10	22	1
11	C 1	C 1	C 3	C 4	SE 6	C 1	C 1	C 4	SE 24	SE 27	SSE 22	S 18	SSE 16	SSW 16	SSE 18	SE 21	SSE 23	SE 19	SE 19	SE 16	SE 16	SE 11	SE 10	SE 9	13	27	1
12	SE 11	C 3	C 1	C 2	C 4	ESE 10	SE 12	SE 10	SE 16	SSE 22	SSE 27	SSE 22	SE 22	SSE 21	SSE 22	SSE 26	SE 23	SE 15	SE 19	SE 14	SE 13	SE 15	SE 14	SE 13	13	27	1
13	ESE 12	SE 10	C 1	C 1	C 2	SE 5	SE 7	SE 10	SSE 15	SSE 18	SSE 18	SSE 20	SSE 22	SSE 22	SSE 18	SSE 18	SSE 24	SSE 21	SSE 15	SE 16	SE 12	SE 6	C 4	SE 6	13	24	1
14	SE 12	SE 19	SE 16	SE 10	ESE 11	SE 5	C 2	SE 10	SE 16	SE 21	SSE 23	SSE 23	SSE 18	SSE 19	SE 22	SSE 22	SSE 20	SSE 17	SE 17	SE 16	SE 15	SE 8	SE 7	SE 8	15	23	2
15	SE 5	SE 6	SE 9	SE 5	SE 8	SE 7	SE 6	SE 11	SE 17	SE 23	SSE 23	SSE 26	SE 22	SSE 20	SSE 24	SSE 25	SE 20	SE 20	SE 16	SE 14	SE 7	SE 9	SE 12	SE 13	15	26	5

CHAPTER 5 MEASUREMENT OF SOLAR RADIATION AND NET RADIATION

For environmental assessment, it is one of the important factors to obtain diffusion coefficient of the survey area by calculating the diffusion of smoke quantitatively. For this purpose, it is also important to obtain the atmospheric stability which is closely related to the diffusion of smoke.

The atmospheric stability is defined by the vertical distribution of temperature, but the continuous and long term measurement of vertical distribution of temperature (upto 1,000 meter high) has the difficulties to be performed. The stability is also influenced by wind velocity considerably and other factors are also not regardless. Pasquill developed the method to classify the atmospheric stability from A to F from wind velocity, solar radiation and cloud volume (substituted by net radiation), and the method has been employed by the Meteorological Department of English Government.

In this study, the stability has been obtained by measuring solar radiation and net radiation of the survey area, together with the wind velocity measured at 7 stations.

The measurement has been carried out for one year, from July 15th 1981 to July 14th 1982. The automatic measuring instruments have been installed at MP-1 and instantaneous and one hour integrated value of solar and net radiation have been recorded. During the above one year, the daily check and maintenance of instruments of once every 3 months have been carried out.

II-5-1 Measuring Methods of Solar and Net Radiation

Most of the radiation energy from the sun are in the wave range of under 4μ. and the instruments to measure such solar radiation is usually called a pyrheliometer and or pyranometer. The pyrheliometer is designed to measure the energy of solar radiation reaching directly to the ground from the sun through atmosphere. It is also designed to avoid the indirect radiation and reflection from the ground, and to trace the sun which is always moving.

The pyranometer is designed to measure all solar radiation, direct and indirect. It is usually used for the purpose of obtaining atmospheric stability. The typical pyranometers have been developed by Robitzsch, Moll and Eppley.

Solar radiation meter is based on the principle to detect temperature difference caused by solar radiation absorbed into the surface of white and black plates by the bimetal or thermocouple.

The net radiation meter is to measure the temperature difference between radiation of two opposite directions, upward and downward.

II-5-2 Instruments Used in This Study for Measurement of Solar and Net Radiation

II-5-2-1 Solar radiation meter

The solar radiation meter used in this study is Eppley type pyranometer which is widely used in Japan. The specifications of the instrument are shown in Table II-5-1 and the sensor is shown in Fig. II-5-1.

Table II-5-1 Specifications of pyranometer used in this study

Sensitivity	7 mV/cal cm^{-2} $min.^{-1}$
Internal resistance	100 Ω
Response speed	3.8 s. (63.2%)
Error by temperature fluctuation	-0.1%/°C
Cosin characteristics	2%
Directional function	all round
Weight	2.31 kg

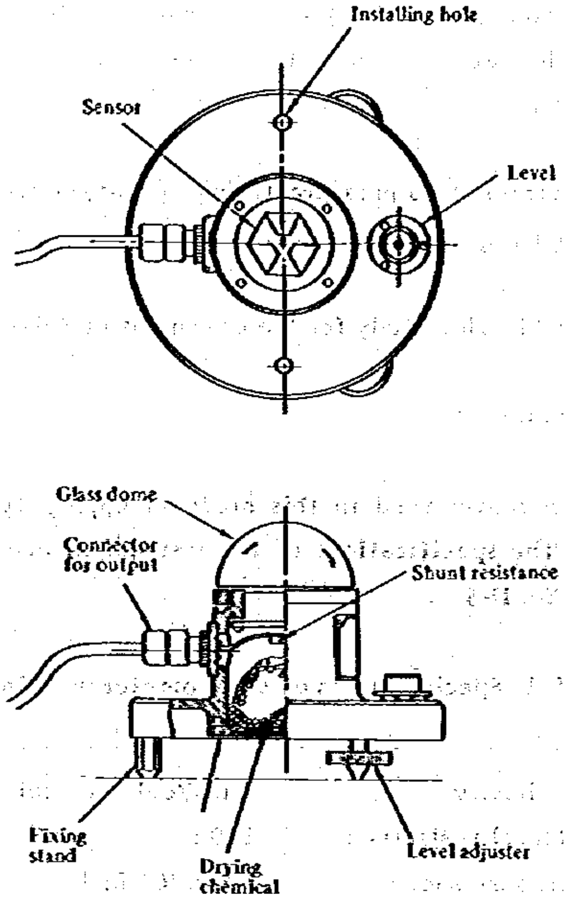


Fig. II-5-1 Sensor of pyranometer

The structure of sensing device is shown in Fig. II-5-2. The white and black plates are installed in radial ways from the center and solar radiation is measured by the temperature difference of two plates. The sensing device is composed by 39 copper/constantan thermocouples, and the white plate is painted by sulfate of barium which is highly effective against humidity and reflectable. The black plate is painted by parsons optical black. In order to avoid the impact by the sudden change of temperature and impact from the wind, the upper side of the sensor is covered by glass dome as shown in Fig. II-5-3. Inside the dome, silicagel is installed for avoiding blur of the glass. The measured radiation is recorded in the recorder by the unit of instantaneous value and one hour value as shown in Picture II-5-1.

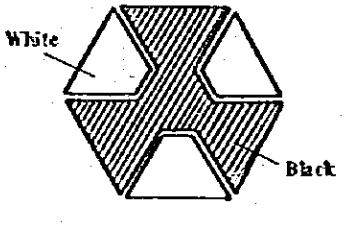


Fig. II-5-2 Sensor of pyranometer

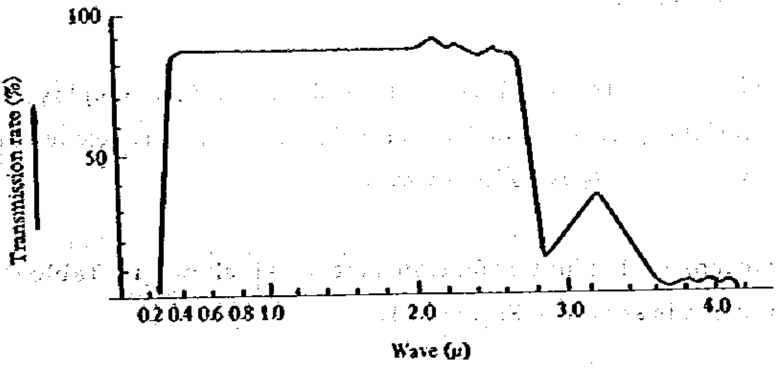
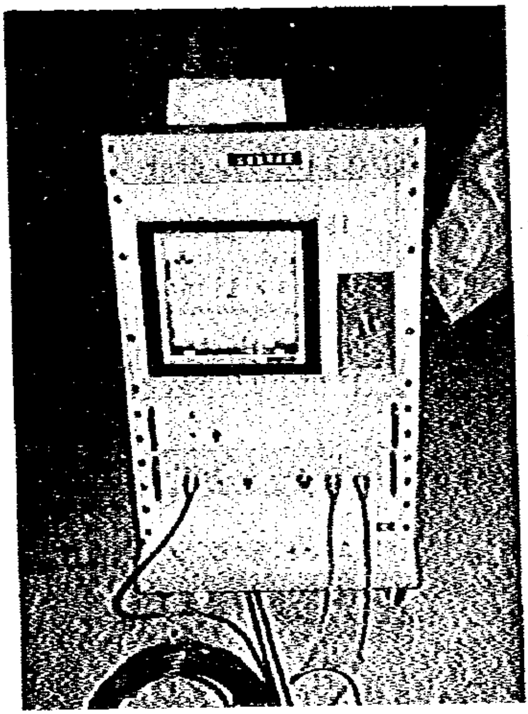


Fig. II-5-3 Transmitting characteristics of glass dome



Picture II-5-1 Shunt box and recorder of pyranometer and net radiation meter

II-5-2-2 Net radiation meter

The net radiation meter used in this study is widely employed in the field of meteorology, agriculture, hygiene and other science which are closely concerned to net radiation in the range from short to long wave.

The specifications of the net radiation meter are shown in Table II-5-2 and the out view of the instrument is shown in Fig. II-5-4.

Table II-5-2 Specifications of net radiation meter

Power	25 mV/cal. Cm^{-2} $min.^{-1}$
Sensitivity difference	within 3%
Internal resistance	80 Ω
Response speed	20 s.
Wave range	0.3 to 100μ over
Temperature range	-15°C to +40°C
Sensor dimension	38 mm x 38 mm
Polyethylene dome	0.1 mm thick, transmitting characteristics as shown in Fig. II-5-5

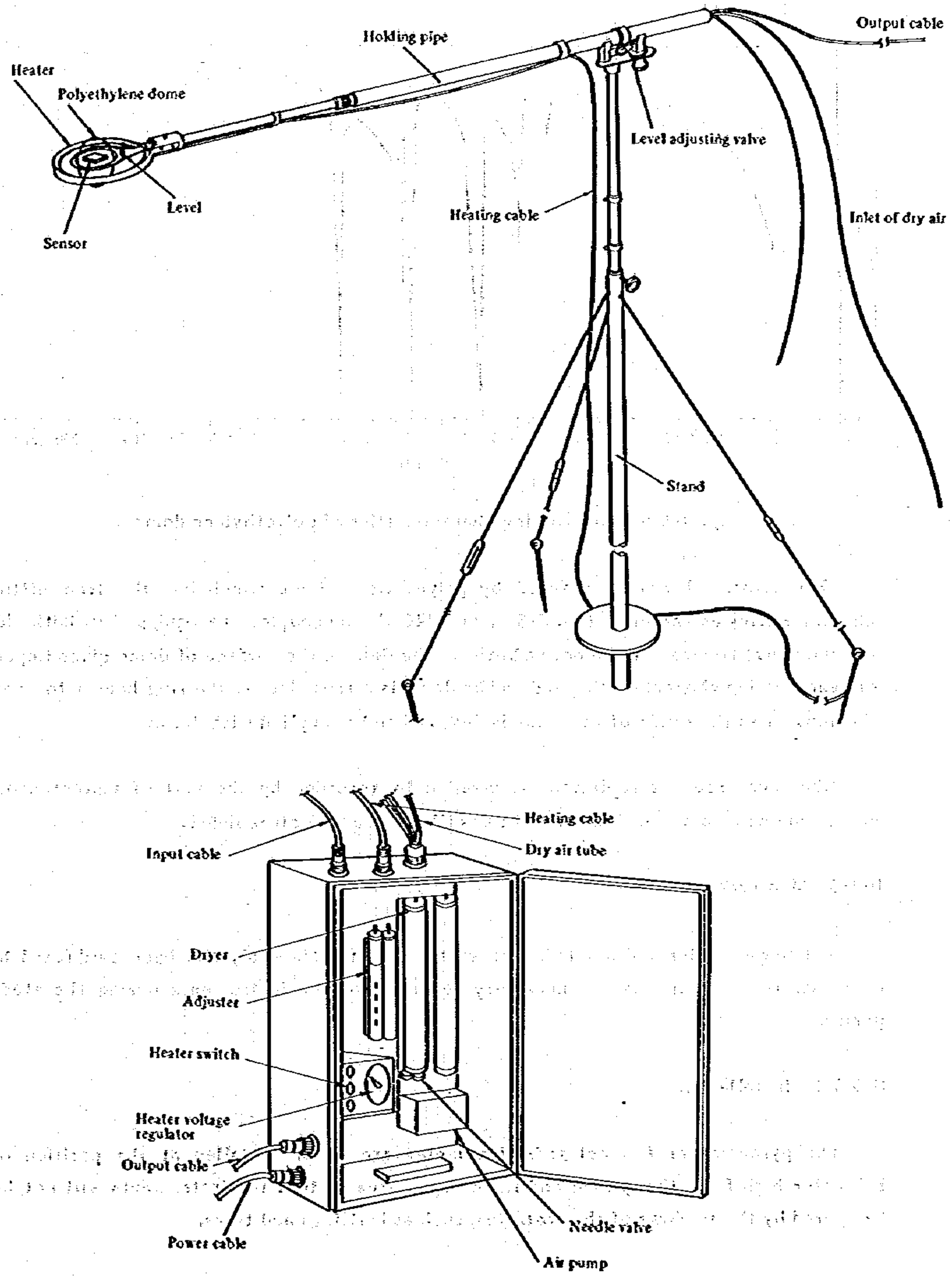


Fig. II-5-4 Outview of net radiation meter

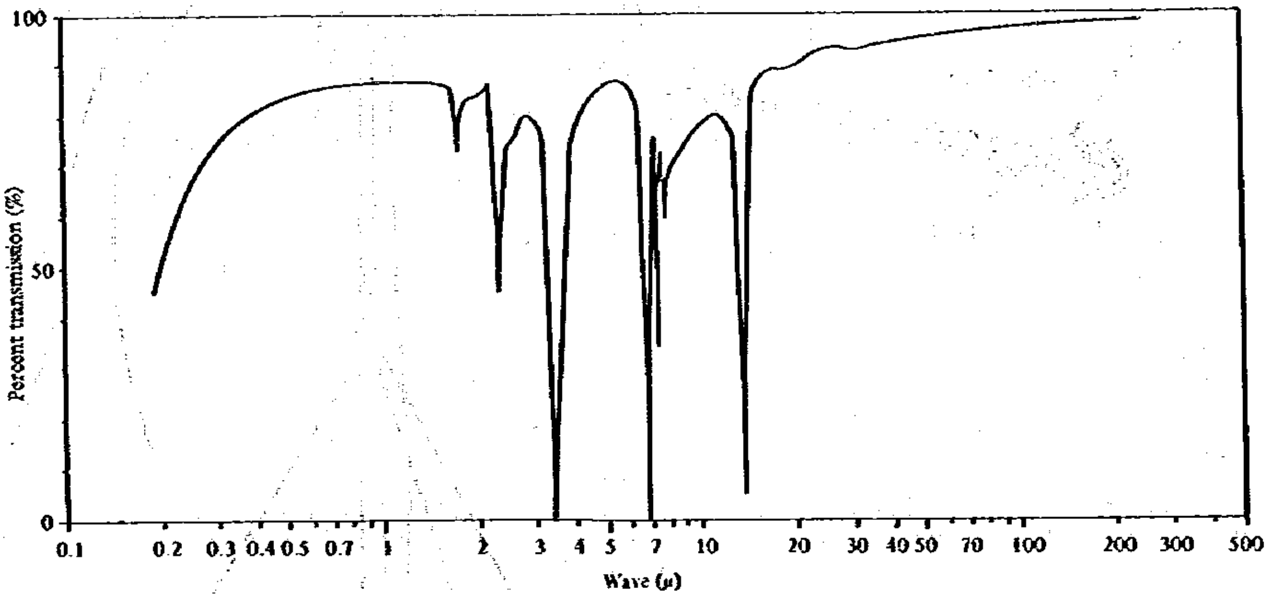


Fig. II-5-5 Transmitting characteristics of polyethylene dome

The sensing device is covered by polyethylene dome which has the transmitting characteristics as shown in Fig. II-5-5, and 240 thermocouples are equipped in both side (up and down) to measure the net radiation. The dew on the surface of dome gives impact on transmitting characteristics and so the dome is surrounded by the ring heater to avoid the dew. Also the inside of the dome is designed to be supplied with dry air.

The measured net radiation is recorded by recorder by the unit of instantaneous value and one hour value through shunt box illustrated in Picture II-5-1.

II-5-3 Measurement

The pyranometer and net radiation meter used in this study had been calibrated by manufacturers and it was not necessary to calibrate the instruments during the study period.

II-5-3-1 Installation

The pyranometer and net radiation meter are to be installed at the position of 1.5 meter high from the ground and in the open area so that the instruments will not be hampered by the shadows of the obstacles, such as buildings and trees.

For the measurement of net radiation, the status of the ground surface is keenly concerned, and so it is usually installed on the ground covered by flat grass.

For installation of instruments, the adjustment of level is very important. In order to secure the constant flow of dry air into polyethylene dome of net radiation meter, the silicon tube of combination cable is connected with the outlet of needle valve of air pump and other end is connected with adjuster in which 80% of water is stored. Turn the needle valve and adjust the bubbling of the adjuster so that 10 to 20 bubbles per minute may be maintained. (refer to Fig. II-5-4.)

II-5-3-2 Connection

The sensors of pyranometer and net radiation meter are connected with recorder through shunt box by cable. The cable extending on the ground is to be buried in the ground to avoid the traffic troubles.

II-5-3-3 Loading of chart

The recorder of pyranometer and net radiation meter are the same type with the one of SO_2 analyzer. The loading of chart has already described in II-3-3-3.

II-5-3-4 Calibration

As described, the calibration of instruments used in this study had been calibrated by the manufacturers and so it was not necessary to calibrate them during the study period. Different from the case of SO_2 analyzer, pyranometer and net radiation meter are usually used for longer term without calibration although regular calibration is recommendable.

II-5-3-5 Automatic measurement

Turn the function selector of shunt box to one hour value and adjust the pen on the present time of chart. Then automatic measurement of solar and net radiation is commenced.

II-5-3-6 Maintenance

In order to secure the sound and proper operation of instruments, the regular maintenance is necessary. The items and frequency for the maintenance are shown in Table II-5-3.

Table II-5-3 Items and frequency of maintenance

Items			Frequency			
Objective		Contents	Daily	Weekly	Month	Whenever necessary
Pyranometer	1) pole	confirm vertical erection	x			
	2) glass dome	blur or damage	x			
	3) silicagel	supply or replacement				x
Net radiation meter	1) pole	confirm vertical erection	x			
	2) polyethylene dome	blur or damage	x			
		tension of dome surface	x			
		replacement of dome			x	
	3) air pump	confirm flow rate	x			
		replacement of silicagel				x
Recorder	1) recorder	confirm chart advance	x			
		confirm time slip of chart	x			
		check ink shade	x			
		replacement of chart			x	
		supply of ink		x		
	2) power supply & connection	confirm loose and disconnection	x			

II-5-4 Results of Maintenance of Measurement

The measurement of solar and net radiation have been carried out at MP-1 shown in Fig. II-1-1 for one year during July 15th 1981 to July 14th 1982 by automatic monitoring instruments. During the survey period, the daily maintenance of instruments have been conducted by JTC and adjustment has been performed by Japanese team for 3 times.

II-5-4-1 Maintenance

(1) Daily check

According to the items and frequency for the maintenance shown in Table II-5-3, the daily maintenance on the following items have been carried out by JTC.

(a) confirmation of vertical erection of poles

(b) check of blur or damage of glass dome of pyranometer

(c) check of blur or damage of polyethylene dome of net radiation meter and also tension of dome

(d) confirmation of chart advance

(e) confirmation of time slip or shift of chart

(f) ink shade and supply of ink

(g) confirmation of loose or disconnection of power cable

Besides the above, the replacement of silicagel and charts have been conducted by JTC.

(2) Maintenance by Japanese team

Once every 3 months, the maintenance by Japanese team has been conducted for the sound and proper operations of instruments. The adjustment of the instruments have been carried out all together 5 times including the times of commencement and completion. Through the maintenance, it was confirmed that the measurement of solar and net radiation has been performed in satisfactory condition.

Table II-5-4 Form for maintenance of pyranometer, net radiation meter and thermometer

THERMOMETER, PYRANOMETER & NET RADIATION METER MAINTENANCE REPORT (Every 3 months)

Month/day ___/___ Time ______ Weather ______ Surveyor ________ Station: MP-______

Thermometer maintenance		Pyranometer maintenance		Net radiation meter maintenance	
Maintenance items	Result	Maintenance items	Result	Maintenance items	Result
Operating condition	Good No	Operating condition	Good No	Operating condition	Good No
Chart printing	Good No	Chart printing	Good No	Chart printing	Good No
Chart slip	min/h	Chart slip	min/h	Chart slip	min/h
Abnormal sound of venti-motor	Yes No	Dome condition	Good No	Dome condition	Good No
Abnormal vibration of venti-motor	Yes No	Silicagel condition	Good No	Silicagel condition	Good No
Venti-duct cleaning	Yes No	Pole condition	Good No	Pole condition	Good No
Check of the temperature monitoring thermometer Temperature 1.5 m 10 m Standard thermometer Temperature 1.5 m 10 m Humidity at the ground	 °C °C °C °C %	Confirmation of level	Good No	Confirmation of level	Good No
		Replacement of silicagel	Yes No	Voltage of transformer	V.
		Remarks:		Disconnection to heater	Yes No
				Pump condition	Good No
				Replacement of silicagel	Yes No
				Replacement of dome	Yes No
				Adjustment of air pump	Yes No
Remarks:				Remarks:	

II-5-4-2 Solar and net radiation

(1) Reading of chart of pyranometer and net radiation meter

As shown in Fig. II-5-6, the solar and net radiation are recorded on the same chart in instantaneous and one hour values respectively. The integrated value is shown by saw teeth as same as SO_2 analyzer, and the top of saw teeth is one hour integrated value. The full scale of chart for solar and net radiation is -10 to 90 cal. $Cm^{-2}.hr^{-1}$(integrated value) and -0.2 to 1.8 cal. $Cm^{-2}.hr^{-1}$(instantaneous value), and the net radiation of night time usually indicates negative value.

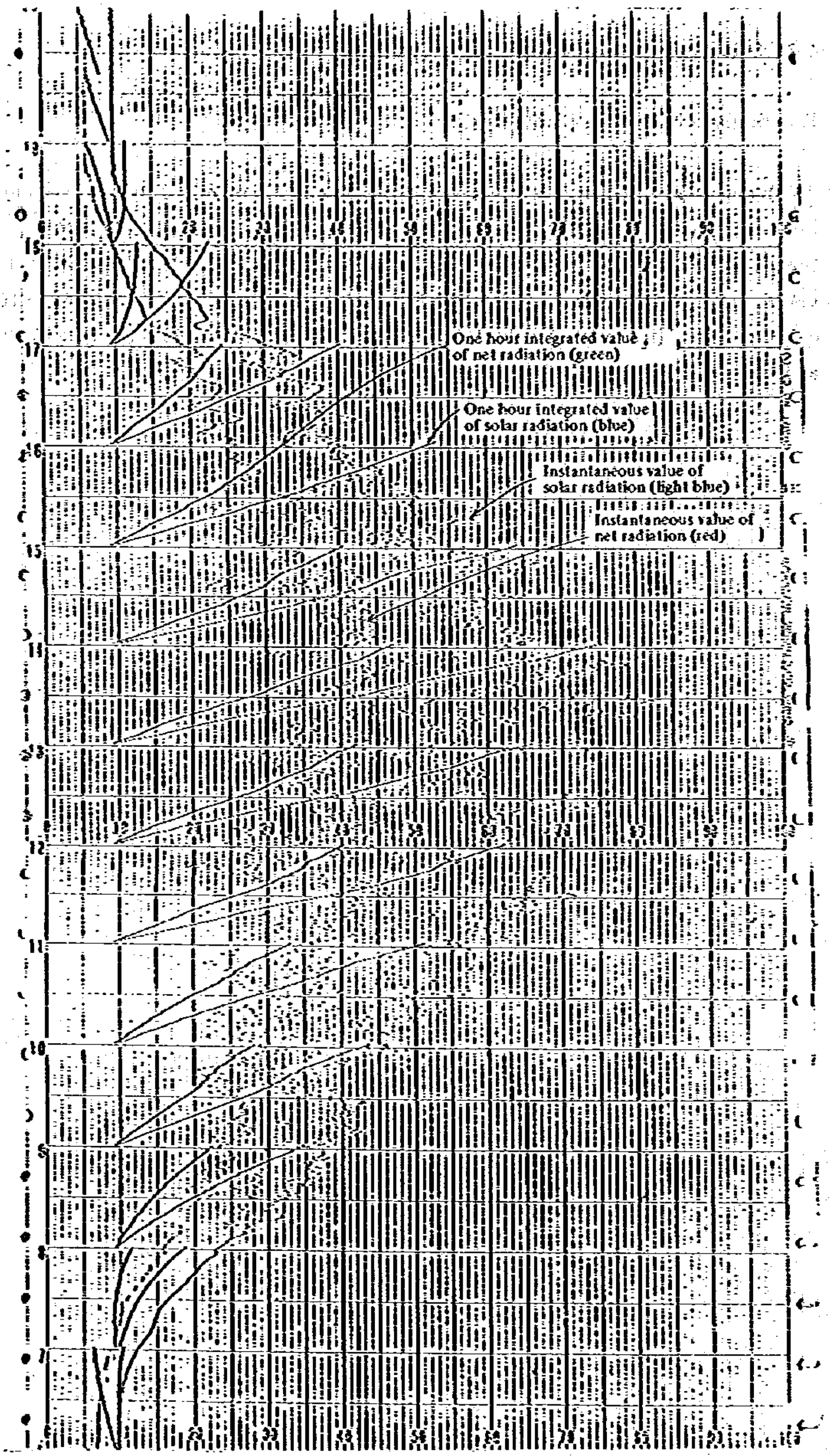


Fig. II-5-6 An example of recording of solar and net radiation

(2) The results of measurement

The effective time of measurement of solar and net radiation in this study was 8,514 hours for solar radiation and 8,067 hours for net radiation. Both of these number of hours are largely exceeding the standard for the effective monitoring station.

The raw data of one hour value of solar and net radiation are shown in ANNEX and an example is shown in Table II-5-5.

The daily profile of solar and net radiation obtained by averaging the data of the same time through the survey period is shown in Fig. II-5-7. The values of 13:00 hour show the maximum in the day.

The analytical results of solar and net radiation, and the relation with the atmospheric stability are described in PART IV.

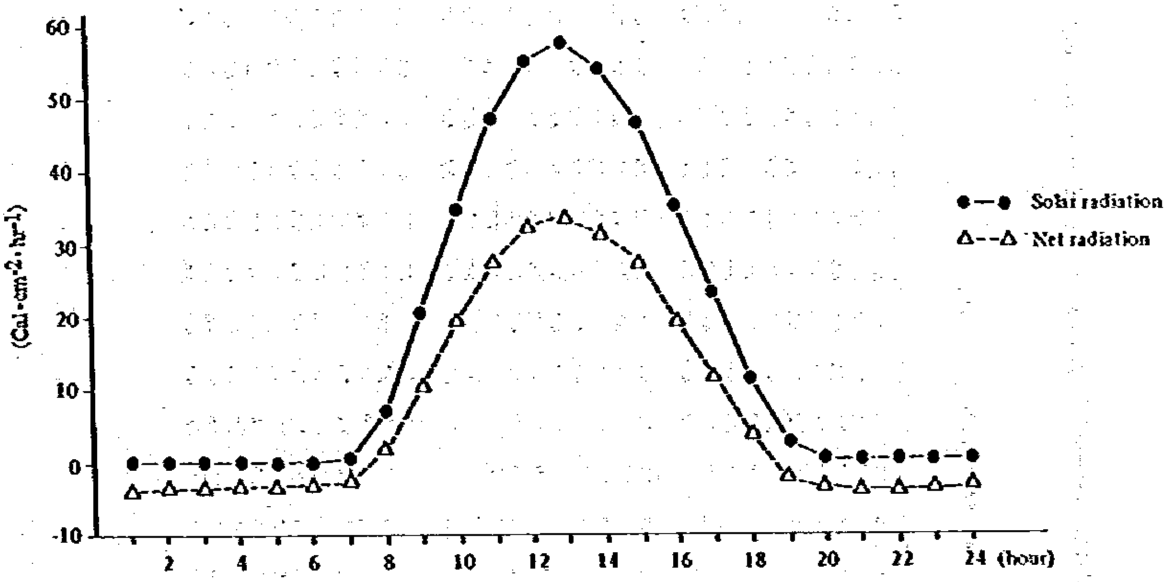


Fig. II-5-7 Hourly fluctuation of solar and net radiation

Table II-5-5-(1) An example of one hour value of solar radiation

SINGAPORE
1961. 8.

SOLAR RADIATION ST. 1

100.0%

DAY	1H	2H	3H	4H	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H	21H	22H	23H	24H	MEAN	MAX	MIN
1	0	0	0	0	0	0	0	11	33	21	25	68	63	27	40	39	11	7	0	0	0	0	0	0	14	68	0
2	0	0	0	0	0	0	1	7	11	11	8	22	30	73	69	59	40	20	3	0	0	0	0	0	15	73	0
3	0	0	0	0	0	0	0	7	23	34	41	65	79	70	51	44	33	12	2	0	0	0	0	0	19	79	0
4	0	0	0	0	0	0	0	8	16	36	58	67	76	65	47	42	32	15	2	0	0	0	0	0	19	76	0
5	0	0	0	0	0	0	0	9	22	42	64	60	71	75	65	54	33	11	0	0	0	0	0	0	21	75	0
6	0	0	0	0	0	0	0	14	30	41	61	70	68	57	59	46	34	16	1	0	0	0	0	0	21	70	0
7	0	0	0	0	0	0	0	8	39	47	40	79	83	80	69	55	36	14	1	0	0	0	0	0	23	83	0
8	0	0	0	0	0	0	1	11	29	49	49	80	83	79	64	53	35	12	1	0	0	0	0	0	23	83	0
9	0	0	0	0	0	0	0	9	24	33	41	52	56	65	54	42	30	13	1	0	0	0	0	0	18	65	0
10	0	0	0	0	0	0	0	8	28	46	69	73	78	65	52	30	25	14	2	0	0	0	0	0	20	78	0
11	0	0	0	0	0	0	1	11	29	51	66	70	82	79	65	51	41	11	1	0	0	0	0	0	24	82	0
12	0	0	0	0	0	0	0	13	28	46	65	77	81	79	67	55	36	16	1	0	0	0	0	0	24	81	0
13	0	0	0	0	0	0	1	11	26	50	64	80	75	73	71	58	39	19	2	0	0	0	0	0	24	80	0
14	0	0	0	0	0	0	1	9	29	47	67	80	82	77	67	57	38	11	2	0	0	0	0	0	24	82	0
15	0	0	0	0	0	0	1	7	27	43	63	64	82	76	66	52	32	16	2	0	0	0	0	0	22	82	0
16	0	0	0	0	0	0	1	9	25	46	52	74	74	60	69	48	29	11	1	0	0	0	0	0	21	74	0
17	0	0	0	0	0	0	0	8	19	32	48	70	70	47	39	48	29	8	1	0	0	0	0	0	17	70	0
18	0	0	0	0	0	0	0	2	6	3	10	39	70	76	63	44	32	11	1	0	0	0	0	0	15	76	0
19	0	0	0	0	0	0	0	8	10	38	55	56	67	58	67	53	32	10	1	0	0	0	0	0	19	67	0
20	0	0	0	0	0	0	1	7	20	20	55	84	76	77	60	48	32	16	1	0	0	0	0	0	21	84	0
21	0	0	0	0	0	0	1	14	31	36	44	71	71	44	70	54	29	11	1	0	0	0	0	0	20	71	0
22	0	0	0	0	0	0	1	13	29	53	66	78	87	84	73	57	25	5	0	0	0	0	0	0	24	87	0
23	0	0	0	0	0	0	1	5	29	55	61	69	74	17	28	48	41	18	1	0	0	0	0	0	19	74	0
24	0	0	0	0	0	0	1	10	14	18	62	72	83	46	39	40	26	11	1	0	0	0	0	0	18	83	0
25	0	0	0	0	0	0	0	8	20	40	46	71	73	40	44	25	13	6	0	0	0	0	0	0	16	73	0
26	0	0	0	0	0	0	1	14	33	50	72	84	90	42	15	8	13	9	1	0	0	0	0	0	18	90	0
27	0	0	0	0	0	0	1	14	34	54	71	85	66	30	6	2	1	2	0	0	0	0	0	0	15	85	0
28	0	0	0	0	0	0	1	13	34	43	68	82	51	47	80	48	37	16	1	0	0	0	0	0	22	82	0
29	0	0	0	0	0	0	1	14	27	29	46	72	90	63	67	61	43	18	1	0	0	0	0	0	22	90	0
30	0	0	0	0	0	0	1	15	36	48	46	73	73	79	26	24	16	10	0	0	0	0	0	0	19	79	0
31	0	0	0	0	0	0	1	9	26	47	43	38	44	66	60	41	34	11	1	0	0	0	0	0	18	66	0
MONTHLY																									20	90	0

UNIT : 0.1CAL/CM**2/HR

Table II-5-5-(2) An example of one hour value of net radiation

SINGAPORE RADIATION ST. 1 98.4%
1981. 8.

DAY	1H	2H	3H	4H	5H	6H	7H	8H	9H	10H	11H	12H	13H	14H	15H	16H	17H	18H	19H	20H	21H	22H	23H	24H	MEAN	MAX	MIN
1	-4	-4	-4	-4	-4	-3	-2	3	10	12	15	42	38	15	23	21	4	2	-3	-5	-5	-4	-5	-5	6	42	-5
2	-4	-4	-4	-3	-3	-3	-1	2	5	7	3	13	17	44	42	30	20	7	-4	-6	-5	-6	-6	-5	6	44	-6
3	-4	-3	-3	-3	-2	-2	-1	2	12	20	25	40	48	41	29	22	16	2	-4	-6	-5	-3	-5	-5	9	48	-6
4	-5	-5	-4	-4	-4	-4	-3	2	8	21	34	40	45	38	27	23	16	5	-4	-6	-6	-5	-5	-5	8	45	-6
5	-4	-3	-3	-2	-2	-2	-2	3	11	24	37	34	41	43	38	27	16	1	-6	-6	-6	-5	-5	-5	9	43	-6
6	-5	-4	-4	-6	-4	-4	-3	5	16	23	35	41													8	41	-5
7	-4	-3	-2	-2	-2	-2	-2	2	15	27	24	47	49	47	39	29	18	3	-5	-6	-5	-5	-5	-5	11	49	-6
8	-4	-5	-5	-6	-5	-5	-4	3	15	28	29	47	40	46	36	29	18	3	-4	-3	-4	-4	-5	-5	10	47	-6
9	-5	-5	-5	-4	-5	-5	-4	2	13	19	23	30	32	37	30	22	15	3	-4	-5	-5	-5	-5	-5	7	37	-5
10	-6	-4	-4	-4	-4	-4	-3	2	14	25	39	42	45	30	18	15	12	3	-5	-6	-6	-6	-5	-5	8	45	-6
11	-4	-4	-3	-3	-3	-3	-2	3	15	28	38	44	48	46	36	27	20	2	-5	-5	-5	-5	-6	-5	11	48	-6
12	-5	-5	-5	-4	-4	-5	-4	4	13	25	37	44	47	45	37	30	17	4	-5	-6	-6	-6	-7	-6	10	47	-7
13	-6	-6	-5	-4	-4	-4	-3	2	12	27	36	45	43	42	39	31	18	5	-5	-6	-6	-6	-5	-5	10	45	-6
14	-5	-6	-6	-6	-5	-5	-3	2	15	25	38	45	46	43	36	30	18	2	-4	-5	-5	-6	-6	-6	10	46	-6
15	-5	-5	-6	-5	-5	-5	-4	1	13	23	36	37	47	43	36	28	15	5	-4	-5	-5	-5	-5	-6	9	47	-6
16	-5	-5	-4	-5	-4	-4	-3	3	12	23	29	41	43	34	37	25	13	2	-4	-5	-5	-5	-5	-5	8	43	-5
17	-5	-5	-5	-4	-4	-4	-3	2	9	17	27	40	40	27	22	26	14	1	-4	-5	-5	-5	-5	-5	7	40	-5
18	-5	-4	-4	-3	-4	-3	-2	0	2	0	5	23	41	43	35	23	16	2	-4	-5	-5	-5	-4	-4	6	43	-5
19	-4	-4	-5	-4	-4	-4	-2	2	5	21	31	32	35	33	37	28	15	1	-4	-4	-5	-5	-4	-4	8	37	-5
20	-4	-4	-4	-3	-3	-3	-1	2	10	11	32	49	44	44	34	25	15	4	-4	-5	-5	-4	-4	-4	9	49	-5
21	-4	-4	-4	-4	-4	-4	-3	4	15	21	25	42	41	24	39	29	13	2	-4	-5	-5	-5	-5	-5	8	42	-5
22	-5	-4	-3	-3	-2	-2	-1	7	15	29	39	45	50	48	41	31	11	-2	-4	-3	-3	-4	-5	-5	11	50	-5
23	-4	-5	-5	-4	-4	-4	-3	1	15	31	35	40	43	9	15	25	20	6	-4	-5	-5	-5	-5	-5	8	43	-5
24	-5	-5	-4	-4	-3	-2	-2	4	7	9	35	42	49	25	21	21	12	2	-3	-3	-3	-2	-5	-3	8	49	-5
25	-5	-3	-4	-4	-4	-4	-3	2	10	23	27	41	42	23	25	13	5	0	-4	-4	-4	-5	-4	-4	7	42	-5
26	-4	-4	-4	-3	-3	-2	-1	7	18	28	41	49	53	24	6	2	6	2	-4	-4	-5	-5	-4	-5	8	53	-5
27	-5	-4	-4	-3	-3	-2	-1	7	19	31	41	49	38	18	3	-1	-1	-2	-4	-4	-3	-3	-2	-2	7	49	-5
28	-2	-2	-2	-2	-2	-2	-1	6	18	24	40	48	28	26	45	25	17	4	-5	-5	-5	-5	-5	-5	10	48	-5
29	-5	-4	-4	-3	-2	-2	-1	8	15	16	26	42	53	36	38	33	22	6	-5	-5	-5	-5	-5	-5	10	53	-5
30	-5	-5	-4	-3	-2	-2	-1	8	19	27	26	42	42	45	14	13	6	2	-3	-5	-5	-5	-4	-4	8	45	-5
31	-4	-4	-3	-4	-3	-3	-2	3	14	27	25	22	26	39	35	22	17	2	-4	-5	-4	-4	-4	-4	8	39	-5
MONTHLY																									8	53	-7

UNIT : 0.1CAL/CM**2/HR