Journal of Environmental Sciences (China), Vol. 2, No. 3, pp 87–98, 1990 ISSN 1001–0742

Application of recording films of solar radiation for environmental and ecological research

YOSHIMURA, Takao[1] and ISHIKAWA, Toshio[1]

(Received December 30, 1989)

Abstract—Global solar radiation is recorded by fading of the colored film into which azo-dye is impregnated with use of organic solvent. Oil Red O, Sudan I, Sudan IV and Pyridylazonaphthol are used as the azo dye. These films can be applied to measure the solar radiation in many kinds of environmental or ecological conditions. The merits of the film compared with usual measurements are to be: unnecessary of any electric sources; cheap and mass-productive easily; suitable to integrate solar radiation for long time; easy dealing in out-door or underwater conditions; possible to use on leaves of any plants because of light weight; possible to use in a lot of points at the same time.

Keywords: global solar radiation; solar radiation sensor; solar energy; dye film; azo-dye.

INTRODUCTION

Sometimes we need to measure the solar radiation by simple methods or without expensive instruments in order to get the information of plant growth, forest management, urban radiation change or global change of solar radiation. Also we need sometimes to measure the solar radiation at many points or at the same time in broad area. We invent a device material which is prepared with cellulose acetate film containing azo-dye and can record integrated radiation by fading of color dye. Now we report the properties and application of this film.

PREPARATION AND PROPERTIES OF THE DYE FILM

Cellulose acetate film is contacted with acetone or methyl ethyl ketone solution of azo-dye, and is swollen by the solvent. Azo-dye penetrates into the film. We can get easily the dye films with uniform optical densities. Fig. 1 shows a coating machine to prepare the dye films. Optical density is measured by spectrophotometer at λ_{max} of the film dye. Fading percentage of each film is related with radiation energy. Table 1 shows four azo-dyes using in our report.

---

[1]Remote Sensing and Image Research Center, Chiba University, Japan.

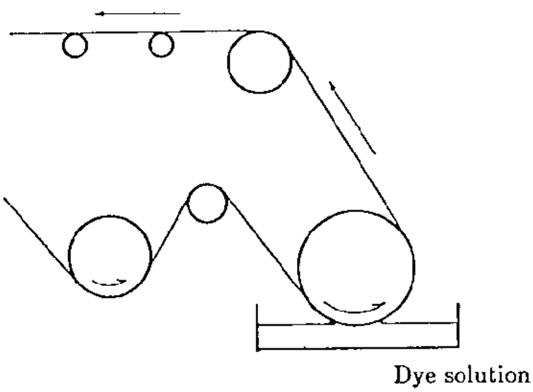


Fig. 1 Impregnating machine

The fading curve in Oil Red O dye film is shown in Fig. 2 from the data for a month. Each film is exposed to solar radiation for a day to a few days, and compared with the values of the authorized radiometer. Fading curve in Sudan IV dye is shown in Fig. 3. Fading of this dye film is slower than Oil Red O about two times. Fading of Sudan I is faster than Sudan IV or PAN (Pyridylazo-2-naphthol) (Fig. 4). We can use Sudan I and Oil Red O films in order to measure the radiation for a day to a few days exposure and Sudan IV and PAN for several days to a few weeks exposure. We tried to check the relation between the fading rates and colors of attaching plates of films (Table 2). The last row is in the case of aluminum plate and the other rows are in the cases of wooden plates. The fading of the films on any plates do not show much different results.

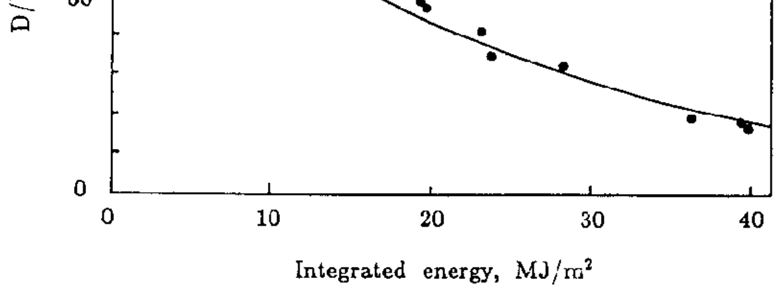


Fig. 2 Fading of irradiated film

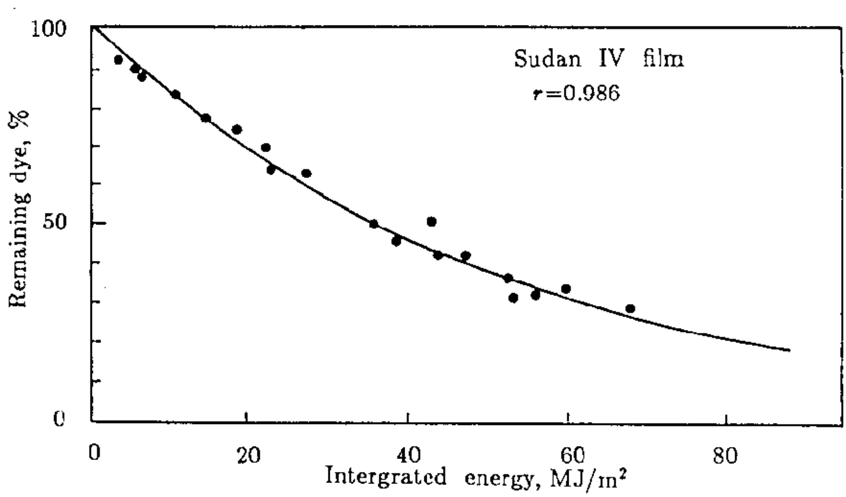


Fig. 3 Fading of irradiated film

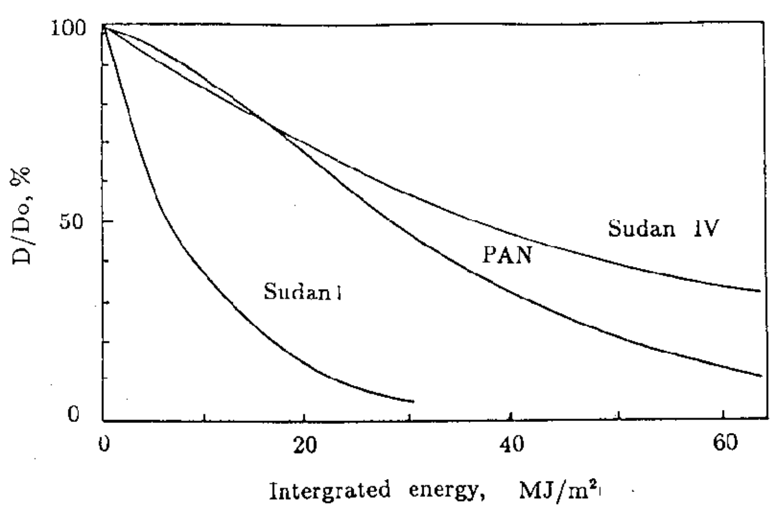
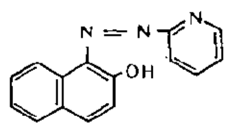
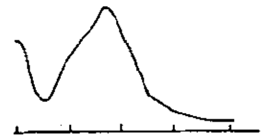
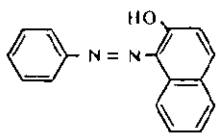
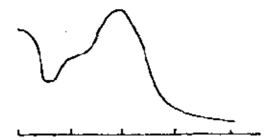
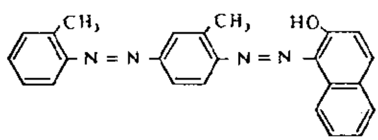
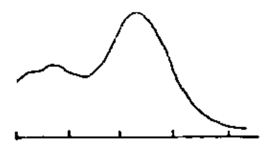
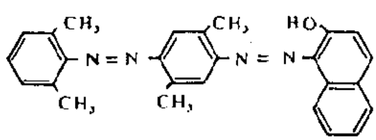
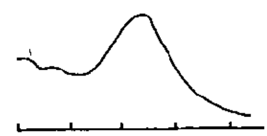


Fig. 4 Fading of irradiated film

Table 1 The spectral adsorption of four azo-dyes

Dye	Formula	Spectral absorption
PAN		
Sudan I		
Sudan IV		
Oil Red O		

We checked the behavior of film fading. Fading of these films does not depend on moisture at normal temperature but depend on the temperature change (Fig. 5). For example, the relation between integrated energy and logarithms of fading percentage shows a linear line and it is depends on the temperature of every season. We have to correct it by calibration curves for temperature dependency. Table 3 shows the slope of fading line related on logarithm of fading ratio and integrated radiation energy on each month. In Japan, August is the hottest season and the slope has the maximum value. December to February show small values because of the cold season. Fig. 6 shows the relation between average temperature and the slopes. We can calculate the slopes of fading curves by next equation using the average normal temperature.

$Y = 3.344 \times 10^{-4} X + 4.62 \times 10^{-3}$,

X : average temperature (°C)

Y ; slope of fading curve (log $(D_0/D)/E(MJ^{-1})$)

Table 2 Reproducibility

	Film No.	Fading Ratio, %	Log (D/Do)
	810	86.327	1.936
	816	86.813	1.939
Black	822	85.808	1.934
	828	85.863	1.933
	834	85.924	1.934
	Avg.	86.105	1.935
	811	87.656	1.934
	817	87.486	1.942
Red	823	87.204	1.941
	829	86.767	1.938
	835	87.561	1.942
	Avg.	87.335	1.941
	812	86.945	1.939
	818	87.752	1.943
Blue	824	85.838	1.934
	830	86.771	1.938
	836	86.642	1.938
	Avg.	86.791	1.938
	813	88.207	1.946
	819	87.261	1.941
White	825	86.614	1.938
	831	85.653	1.933
	837	86.171	1.935
	Avg.	86.781	1.938
	814	88.616	1.948
	820	87.552	1.942
Green	826	87.101	1.940
	832	87.576	1.942
	838	88.243	1.946
	Avg.	87.817	1.944
	815	87.830	1.944
	821	87.308	1.941
Aluminum	827	86.687	1.938
	833	87.256	1.941
	839	86.590	1.937
	Avg.	87.134	1.940

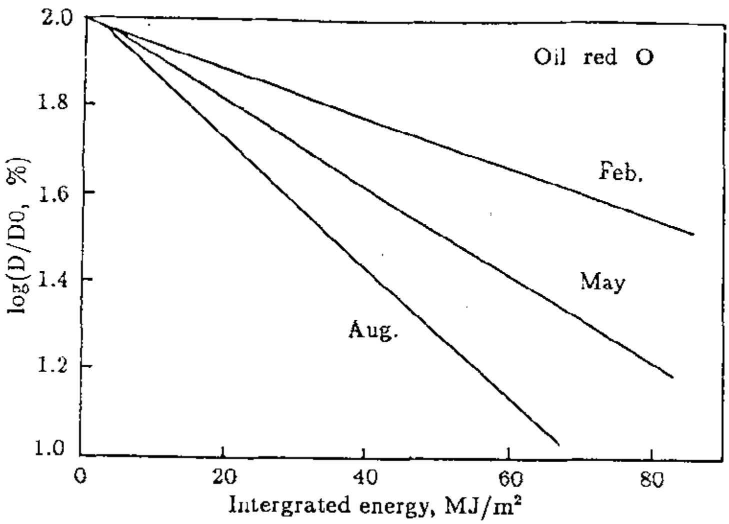


Fig. 5 Integrated energy

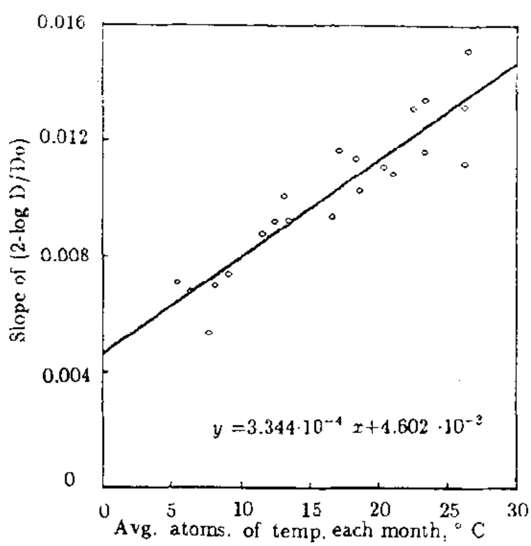


Fig. 6 Relation between average atmosphere temperature and slope of $(2\text{-}\log D/D_0)$

Table 3 Slope of line related on log (D/D_0) and radiated energy on each month

Term	Slope, m^2/MJ	Coefficient of correlation, r	Standard error, MJ/m^2
87.1	0.0071	0.9851	0.561
2	0.0063	0.9721	0.597
3	0.0074	0.9831	1.388
4	0.0092	0.9934	0.769
5	0.0103	0.9946	1.100
6	0.0108	0.9520	1.314
7	0.0131	0.9555	1.460
8	0.0151	0.9907	1.158
9	0.0131	0.9836	1.009
10	0.0113	0.9836	1.009
11	0.0092	0.9859	0.555
12	0.0053	0.9591	0.742

APPLICATIONS

We try to use these films for a few applications. At first we tried to measure the global energy on the ground surface or on leave surface of a tree. Solar energy under the water is also measured for environmental check in lakes. Table 4 shows radiated energy on the leaves of a tree (Japanese name: *Matebashii-Lithocarpus edilis)* standing alone on the ground. We attached each ten films on the leaves facing east, south, west, and north in 1.5m height and 3m height. The maximum solar radiation on the leaves is shown in east and south sides and the minimum is in west and north sides. Standard deviation is maximum in the east side both in 1.5m height and 3m height.

Table 4 Radiated energy on the leaves of a tree (*Lithocarpus edilis*) PAN (exposure term Oct. 8 — Nov. 4)

	East	South	West	North
1.5m high				
Pieces	10	10	10	10
Solar radiation max. (MJ/m^2)	71.7	73.2	46.8	47.8
min.	13.9	40.3	12.9	19.5
avg.	52.9	56.5	32.4	29.6
Standard deviation	17.0	9.3	11.6	7.5
3.0m high				
Pieces	10	10	10	10
Solar radiation max. (MJ/m^2)	80.2	77.9	64.8	62.7
min.	11.8	48.3	18.7	19.5
avg.	51.9	28.2	56.5	42.1
Standard deviation	21.8	9.5	8.7	14.6

An apparatus for underwater measuring with a float, weight and stages is shown in Fig. 7. The upper stage is just controlled about 1cm under the surface of water by change of the weight. The second stage is in 10cm under the surface. The third and fourth stages in 20 and

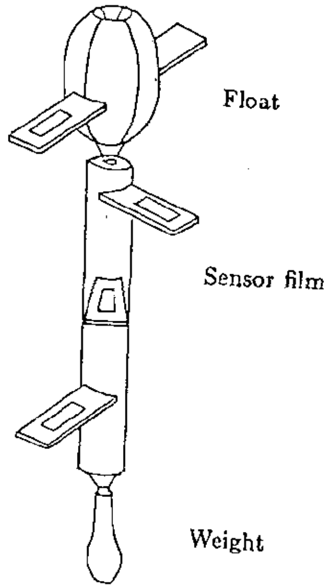


Fig. 7 An apparatus for underwater measuring

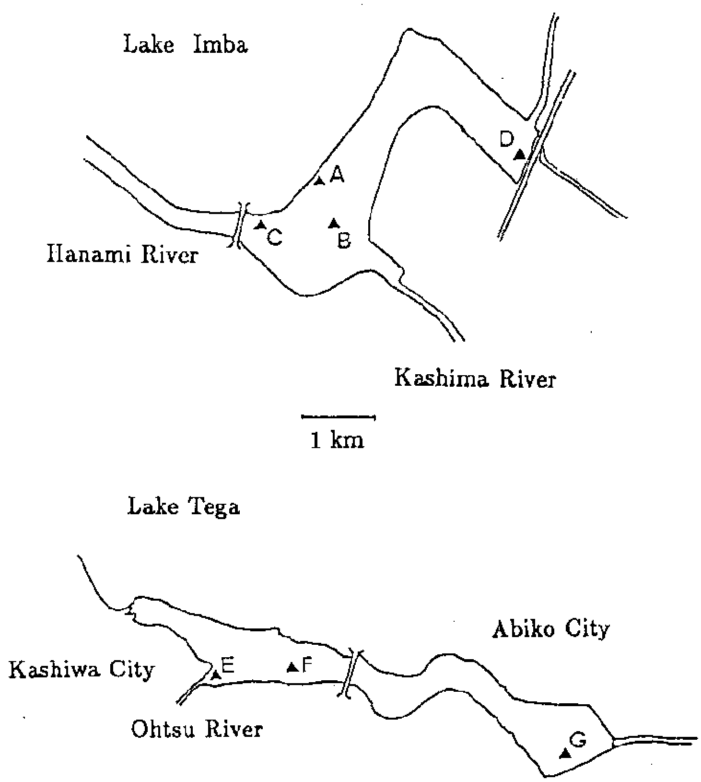


Fig. 8 Measuring points

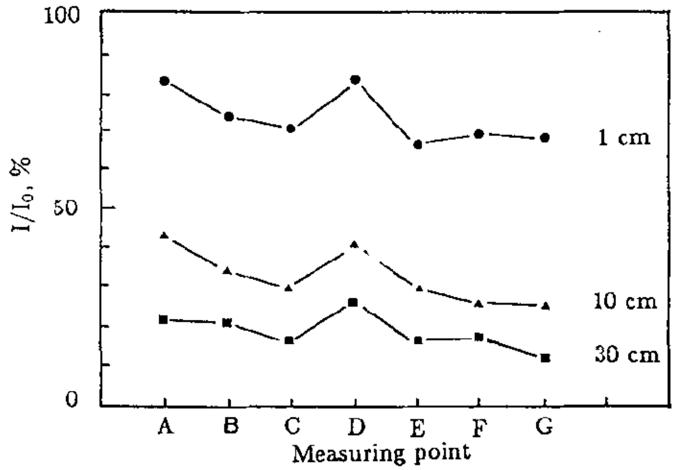


Fig. 9 Variation of underwater radiation at 7 points of Lake Tega and Imba

I_0: radiation on the water I: underwater radiation

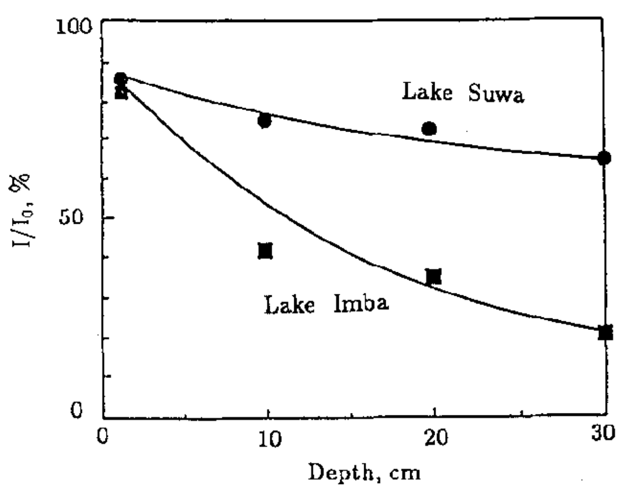


Fig. 10 Relation between underwater radiation ad depth of set films in Lake Suwa and Lake Imba

I_0: radiation on the water I: underwater radiation

30 cm under the surface of water respectively. Another film piece is fading out of the water as the reference. I/I_0 is applied here instead of D/D_0. I and I_0 are the amounts of radiated energy of the underwater films and the reference film respectively. Fig. 8 shows that the test areas of underwater measurements, that are Lake Tega and Lake Imba. Lake Tega is in 30 km northeast and Lake Imba is in 40km east from Tokyo. These two lakes have pretty polluted water. Point A to G are the check points for underwater radiation test in these lakes. Fig. 9

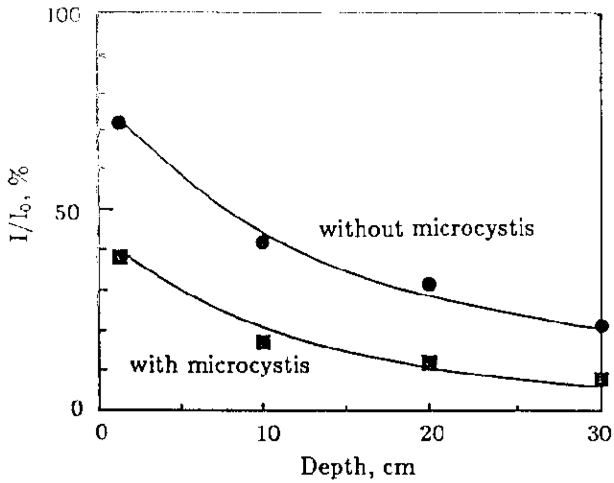


Fig. 11 Relation between underwater radiation and depth of set films with and without microcystis growth

I_0: radiation on the water I: underwater radiation

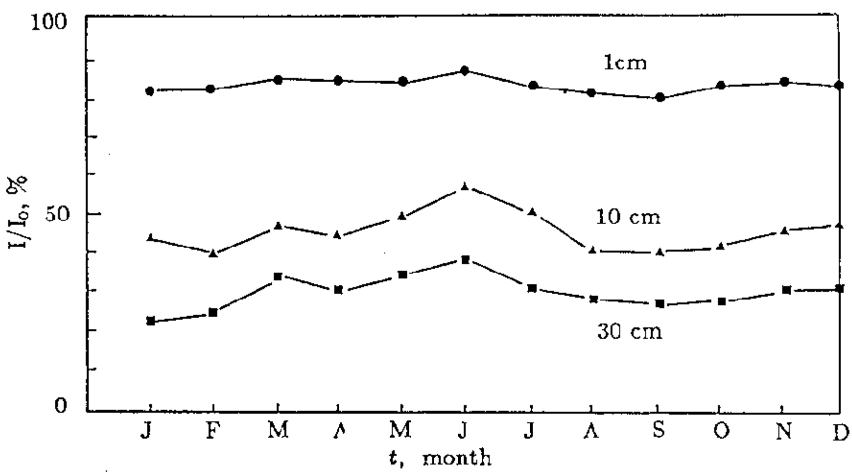


Fig. 12 Change of underwater radiation at point D of Lake Imba

I_0: radiation on the water I: underwater radiation

shows underwater radiation at 7 points (A — G) of Lake Tega and Imba. Point A and D have the best transparency.

We tried to compare two lakes: Lake Suwa and Lake Imba. The former is located in mountain area, Nagano prefecture and the latter is in plain, Chiba prefecture. Fig. 10 shows that the water of Lake Suwa is clearer and better transparency than the water of Lake Imba. Fig. 11 shows that the seasonal change of the water in Lake Tega. The water of Lake Tega

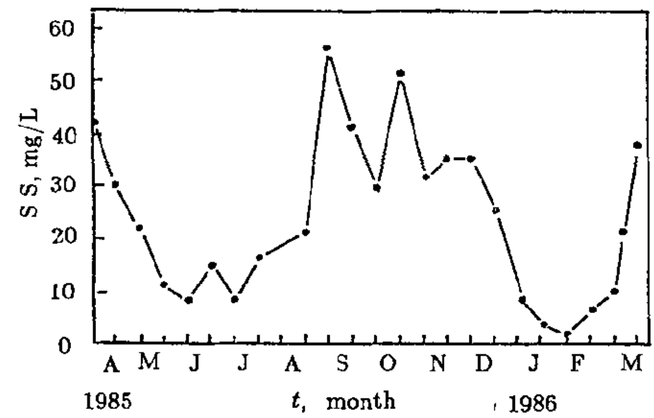


Fig. 13 Seasonal change of suspended substances (SS) in Lake Imba

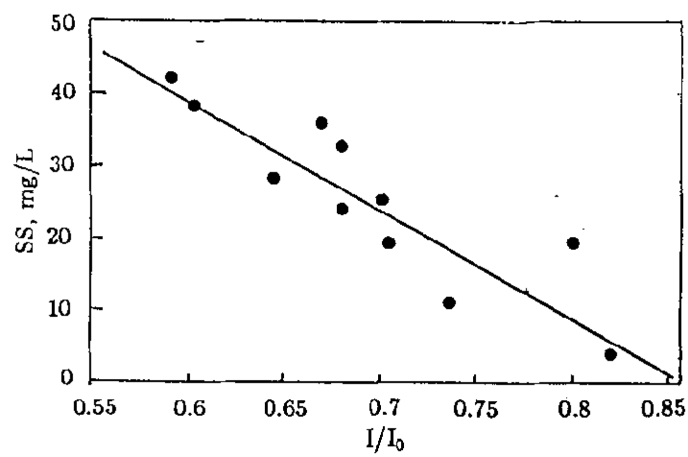


Fig. 14 Relation between suspended substances and underwater radiation

is polluted strongly and sometimes Microcystis, a kind of small algae generates in summer. Therefore the transparency of water becomes very low in summer. The seasonal change of underwater radiation at point D in Lake Imba is shown in Fig. 12. In Japan, June is the rainy season, and incoming water increases therefore the transparency of water becomes high. But in August it is hot weather and sometimes less water, and moreover small algae or microbe generates very much therefore the transparency becomes very low. The seasonal change of suspended substances (SS) in Lake Imba is shown in Fig. 13. We find two peaks and two bottoms in a year. The relation between suspended substances (SS) and underwater radiation is shown in Fig. 14. We can get a straight line with 0.86 as the coefficient of correlation in this case.

We are studying now two applied projects with several researchers in agriculture and ecology. One is the relation between vegetable growth or its harvest and the received solar radiation of vegetable leaves. Another one is the relation between the received radiation of small plants and its growth or its death in the big forest.

CONCLUSION

The global solar radiation is recorded by fading of the dye films. The merits of this film compared with usual measurements are to be: unnecessary of any electric sources in measurement time; cheap and mass-productive easily; suitable to integrate solar radiation for long time; easy dealing in out-door or underwater conditions; possible to use on leaves of any plants because of light weight; possible to use in a lot of points at the same time.

REFERENCES

YOSHIMURA, Takao, KOMIYAMA Katsura and ISHIKAWA, Toshio, Journal of JSES (Japan), 1989, 15(5): 47

H. Mustroph, J. Marx and J. Epperlein, Acta Polymerica, 1983, 34(6): 336