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Oceanic Diffusion Characteristics in Jinhae Bay*

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Diffusion processes in tidal swinging coastal waters are studied by releasing one hundred liters of Rhodamine B four times. Dye patches were formed from instantaneous point sources. The patches were sampled with a pump on a tracking boat, and samples were analyzed with fluorospectro-photometer. The patterns of patches were reconstructed and their characteristics were analyzed in terms of variance of concentration, area estimation, and decrease rate of peak concentration.

In all of the four experiments, the dye patches were mostly elongated to the direction of current axis. the elongation rate was 0.34 on the avarage. Apparent diffusivities were 620 to 3,000 cm^2/sec during initial period of 90 minutes. The variance increased by $\exp(0.047t)$ on the average, and peak concentration decceased by $\exp(-0.044t)$ on the average.

Introduction

The Jinhae bay is located in a distance from the off sea and adjacent to the Masan bay on the north. Much waste water and sewage are discharged into this bay from the near seaside industrial compound and residential area. In addition, the red tides occur frequently in this area in summer. So, the Jinhae bay is regarded as one of the most contaminated bays in Korea. These lead us to investigate characteristics of diffusion in this sea area.

The processes of oceanic diffusion are quite complex, and hardly any single theory can explain or interpret the entire pattern of diffusion. Under the some ideal conditions, thes tudies of diffusion were developed by Taylor (1921) and many others such as Frenkiel (1953), and Townsend and Batchelor(1956). The study of diffusion in a certain area has been made through in *situ* experiments(Inoue(1950, 1951); Olson and Ichiye(1959, 1960); Okubo(1962, 1971)).

In coastal area of Korea, dye diffusion characteristics were investigated by Han and Yoon (1970), Chang(1980), Ro(1980), Kim(1981) and others.

This paper presents some diffusion characteristics, including horizontal variance, apparent diffusivity, and decreace rate of peakconcentration, of the experiments made in the Jinhae bay during the spring and neap tides respectively.

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Material and Methods

Rhodamine B was used as a dye. In order to make a density of dye solution to be the same as that of seawater, 6*kg* of Rhodamine B was dissolved in 34 liters of methanol prior to experiment. This solution was mixed with in *situ* seawater and finally 100 liters of dye solution was prepared in each experiment. The dye solution was released instantaneously at the sea surface at point A and B(Fig. 1) during the spring and neap tides respectively.

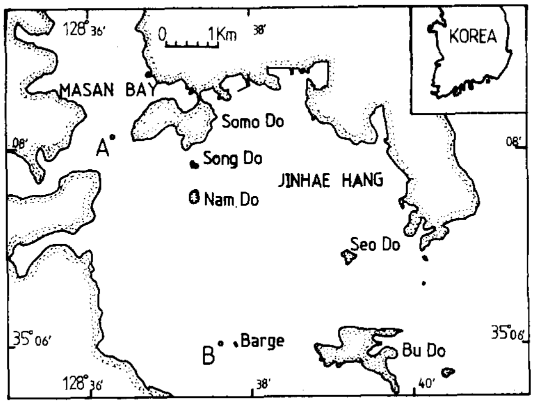

Fig. 1 Dye diffusion experiments station in the Jinhae bay.

Dye patches were tracked on small boats, and dyed water was sampled with the DC pump (3V) along X-axis(major direction of dye patch) and Y-axis(transverse direction).

Spatial and temporal sampling intervals and the numbers of sampling point are shown in Table 1.

The position of the boat was traced by using sextant and magnetic compass. Current direction and speed were obtained with a current meter (Toho Dentan CM2). The wind was measured on the boat. Wind data at the Geoje Auxiliry Weather Station during the same period was used as an auxiliry data of wind. Fluorospectro-photometer(Model ANA-40) was used to measure the concentration of sampled water.

An apparent diffusivity(K_a) is expressed as follows(Okubo, 1971)

$$K_a = \frac{\sigma_{rc}^2}{4t} \quad \cdots\cdots(1)$$

$$\sigma_{rc}^2 = 2\sigma_x\sigma_y \quad \cdots\cdots(2)$$

$$\sigma_x^2 = \frac{1}{Q}\sum(X_i - X_{i-1})^2 C_i,$$

$$\sigma_y^2 = \frac{1}{Q}\sum(Y_j - Y_{j-1})^2 C_j$$

Table 1 Dye diffusion experiments data in the Jinhae bay

Tide	Time of release	Elapsed time (*min*)	Sampled interval(*m*)		No. of Sampling Stations	
			X-axis	Y-axis	X-axis	Y-axis
Ebb flow	11 : 40	30	15	20	10	3
		60	45	25	12	5
		90	50	25	12	8
		120	50	35	15	8
Flood flow	16 : 35	30	15	5	13	6
		60	35	10	13	8
		90	45	15	13	8
		120	55	20	14	9
Flood flow	10 : 35	30	20	5	6	7
		60	40	10	9	8
		90	40	30	9	8
Ebb flow	15 : 05	30	15	5	6	9
		60	20	5	9	12
		90	35	10	9	12

where, σ_{rc}^2: horizontal variance of concentration,

t: elapsed time,

σ_x^2: variance of dye concentration distribution in the X-axis,

σ_y^2: variance of dye concentration distribution in the Y-axis,

Q: the amount of dye solution,

X_i, Y_j: distance between concentration C_i (C_j) and center of mass,

C_i: concentration at(X_i, Y_j),

Elongation rate is defined by the ratio between Y-axis and X-axis of dye patches.

The diffusion length scales 'L' are measured by

$$L = 3\sigma_{rc} \cdots\cdots (3)$$

Results and Discussions

Ocean current and wind data during the experiments in the Jinhae bay are shown in Table 2 and 3, respectively.

Figs. 2 a-d show distributions of dye concentration along the track lines, and Table 4 shows results of diffusion experiments.

Table 2 Ocean current in the Jinhae bay

Date 1981	Time	Speed(cm/sec)	Direction
August 17	12 : 10	5	NE
	12 : 40	25	SSE
	13 : 10	23	SW
	13 : 40	20	SSW
	17 : 05	18	E
	17 : 35	15	ENE
September 7	10 : 35	15	SE
	11 : 05	15	SSE
	11 : 35	2	ENE
	12 : 05	1	NNE
	15 : 05	7	S
	15 : 35	3	ESE
	16 : 05	0	N
	16 : 35	1	N

Table 3 Wind speed and direction in the Jinhae bay

Date 1981	Time	Speed(m/sec)	Direction
August 17	11 : 00	3.0	NE
	12 : 00	3.5	NW
	13 : 00	3.0	SE
	14 : 00	2.5	SE
	16 : 00	1.0	NE
	17 : 00	2.5	NE
	18 : 00	2.5	E
	19 : 00	3.5	S
September 7	10 : 00	2.5	NNE
	11 : 00	2.0	N
	12 : 00	1.0	S
	13 : 00	1.0	S
	15 : 00	3.0	SW
	16 : 00	3.5	SW
	17 : 00	2.0	SE

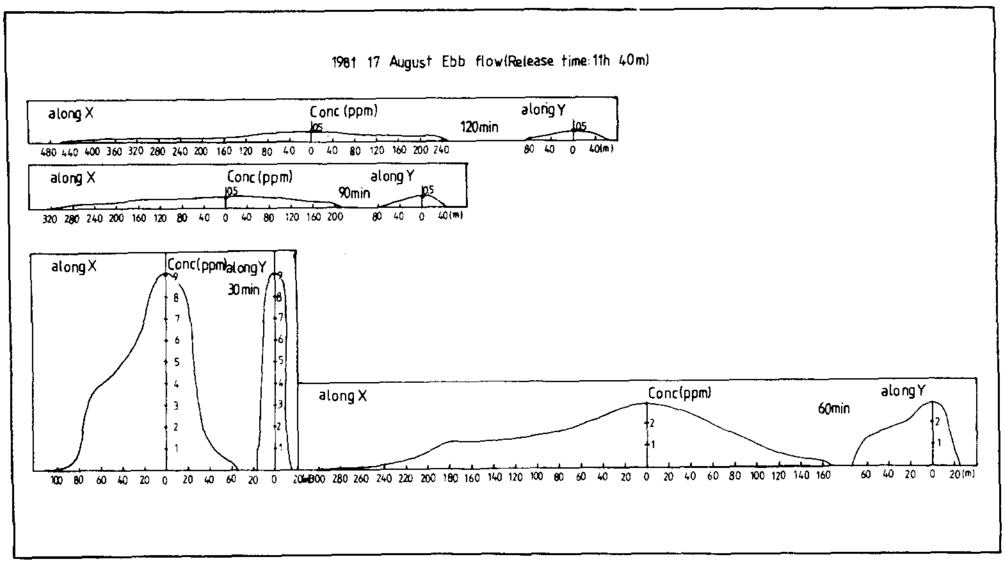

Fig. 2-a Distribution of dye concentration vs distances.

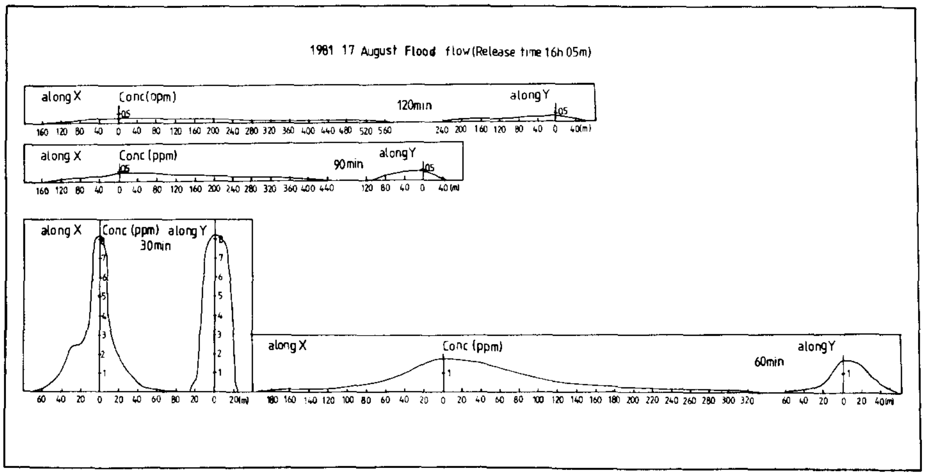

Fig. 2-b Distribution of dye concentration vs distances.

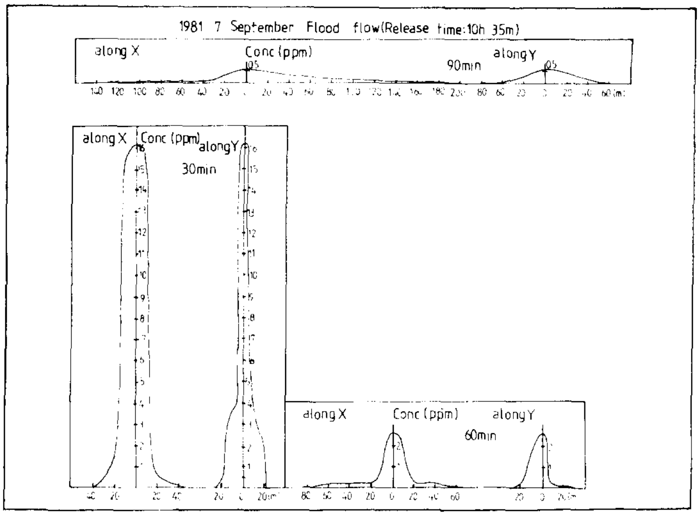

Fig. 2-c Distribution of dye concentration vs distances.

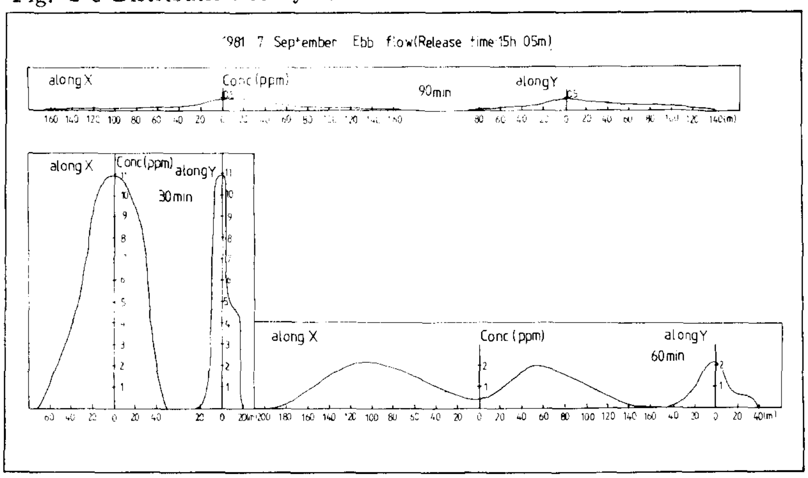

Fig. 2-d Distribution of dye concentration vs distances.

Table 4 Results of the dye diffusion experiments

Exp. No.	Tide	Elapsed time(*min*)	Area (m^2)	Variance(m^2) σ_x^2	Variance(m^2) σ_y^2	σ_{rc}^2 (m^2)	K_a (cm^2/sec)	L (cm)	Width(m) X	Width(m) Y	Peak Conc. (ppm)	Elongation rate
		30	4.6×10^3	401	34	234	3.3×10^2	4.6×10^3	210	30	9.05	0.14
1	Ebb	60	3.5×10^4	2988	257	1753	1.2×10^3	1.3×10^4	470	100	2.94	0.21
	flow	90	5.3×10^4	12500	816	6387	3.0×10^3	2.4×10^4	590	125	0.54	0.21
		120	1.1×10^5	15778	1882	10898	3.8×10^3	3.1×10^4	750	190	0.49	0.25
		30	4.5×10^3	220	61	232	3.2×10^2	4.6×10^3	155	50	8.19	0.32
2	Flood	60	3.5×10^4	4168	220	1915	1.3×10^3	1.3×10^4	530	125	1.77	0.24
	flow	90	7.6×10^4	8979	1054	6153	2.8×10^3	2.4×10^4	605	195	0.45	0.32
		120	1.5×10^5	16605	2021	11586	4.0×10^3	3.2×10^4	735	295	0.31	0.40
		30	2.3×10^3	94	17	80	1.1×10^2	2.7×10^3	85	45	6.17	0.53
3	Flood	60	1.0×10^4	570	63	379	2.6×10^2	5.8×10^3	175	60	2.52	0.34
	flow	90	3.3×10^4	1170	383	1337	6.2×10^2	1.1×10^4	270	120	0.65	0.44
		30	2.7×10^3	227	25	151	2.1×10^2	3.7×10^3	125	45	10.98	0.36
4	Ebb	60	2.0×10^4	587	103	492	3.4×10^2	6.7×10^3	375	80	2.17	0.21
	flow	90	6.3×10^4	3171	1689	4629	2.1×10^3	2.0×10^4	345	250	0.49	0.12

(1) The ebb of spring tide

During the first experiment(on August 17, 1981), there was south southeasterly winds, and the direction of current changed from south westward to south southwestward. The dye patch was a horseshoe-shaped and moved from southwest to westward, as is shown in Fig. 3-a.

Apparent diffusivity at diffusion time 90 minutes was $1.2\times10^3 cm^2/sec$. This figure is considerably smaller than the result of $7\sim8\times10^3 cm^2/sec$ at Kori by Ro(1980). This features can be understood from the fact that the seawater movements in our experimental side have smaller spatial scales.

The average elongation rate was about 0.2.

(2) The flood of spring tide

During the second experiment(on August 17, 1981), current flew from east to north easteastward with the speed of $18 cm/sec$, and wind blew northeasterly with the speed of $2\sim3 m/sec$. The dye patch transported slowly northeastward as shown in Fig. 3-b.

Apparent diffusivity was similar to the result of the ebb flow. The average elongation rate was about 0.32.

(3) The flood of neap tide

As is shown in Fig. 3-c (on September 7, 1981), dye patch was a crescent shaped and moved from southward in beginning stage to northwestward in later stage. It is analyzed that the northerly wind with the speed of $2.5 m/sec$ blew at the beginning and shifted to southerly wind with the speed of $1.0 m/sec$.

Apparent diffusivity of 6.2×10^2 cm^2/sec is small compared to the result at the Suyeong bay (Kim: 1981). At the diffusion time 90 minutes, the sea was very calm like a mirror and the dye patch began to sink slowly.

The average elongation rate was about 0.44.

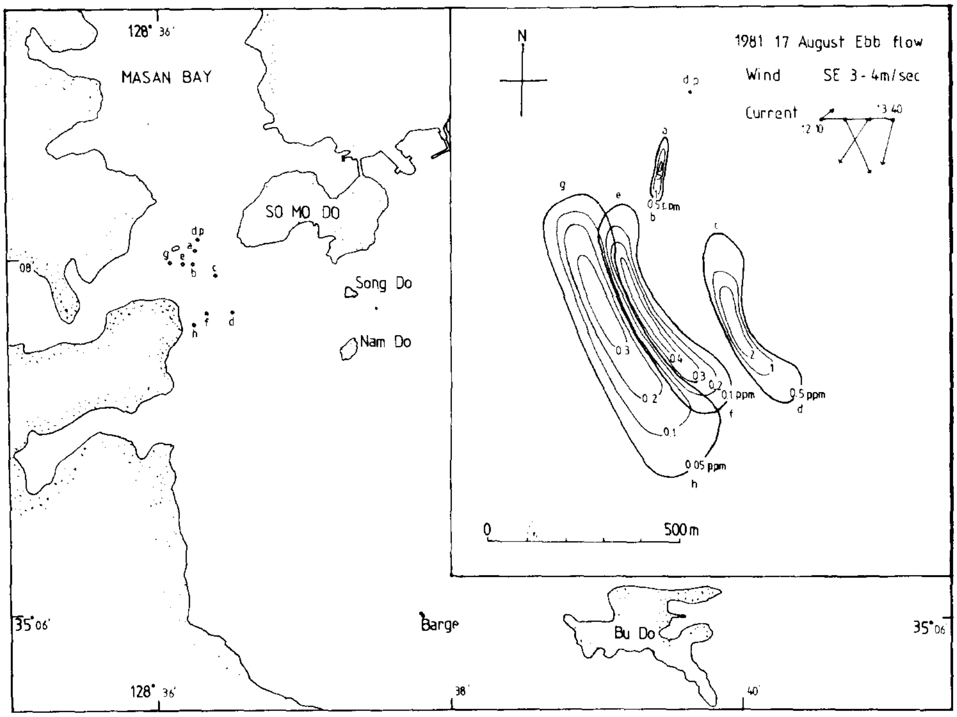

Fig 3-a Patch diagram of ebb flow.

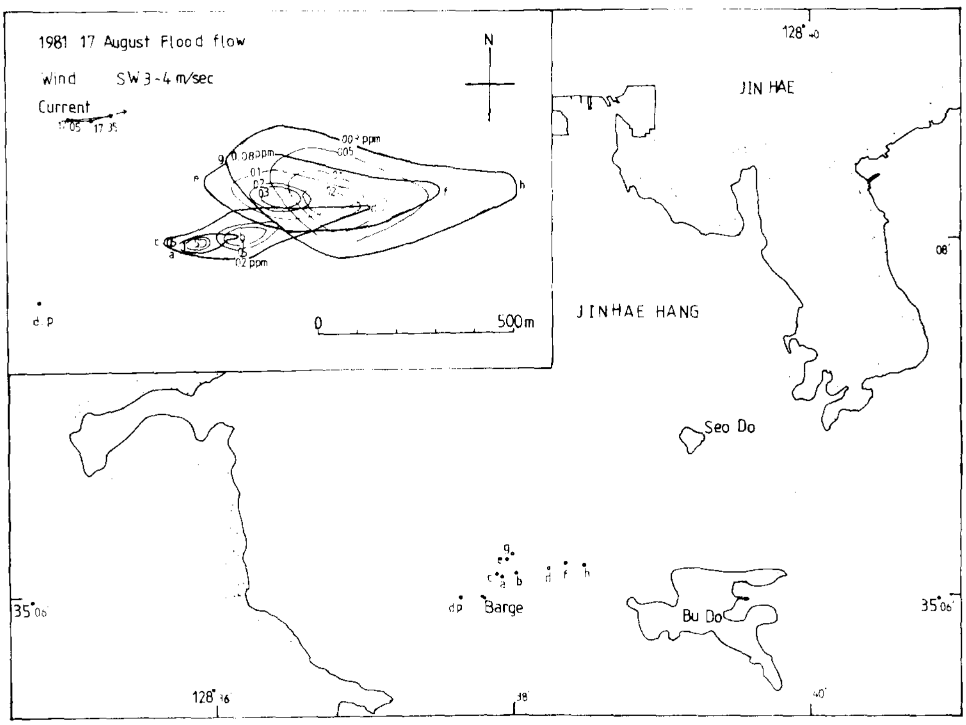

Fig. 3-b Patch diagram of flood flow.

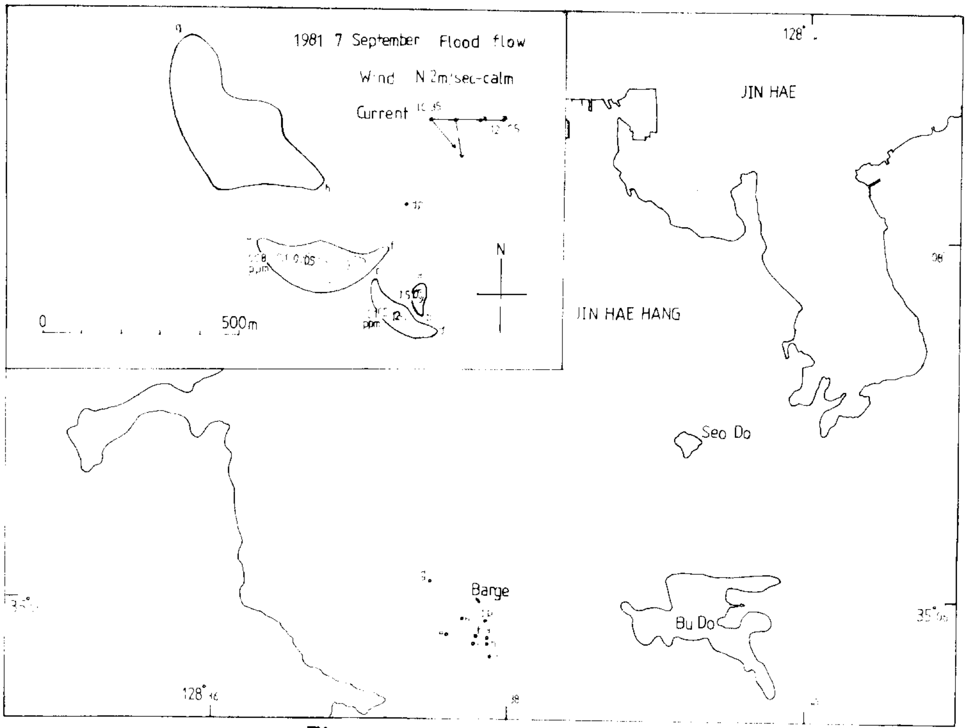

Fig. 3-c Patch diagram of flood flow.

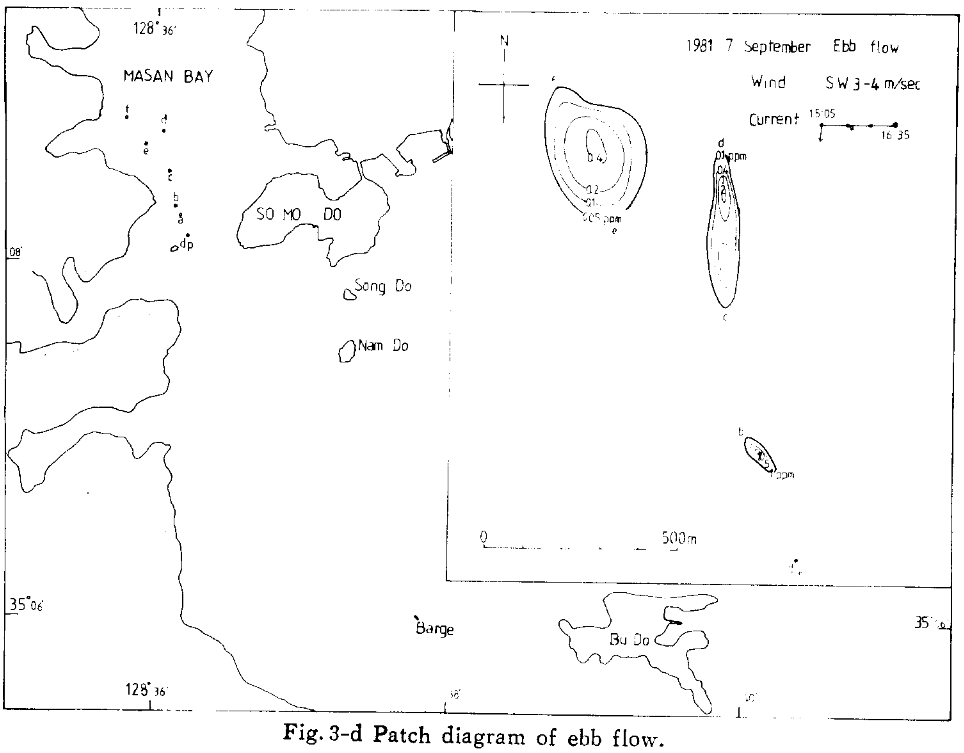

Fig. 3-d Patch diagram of ebb flow.

(4) The ebb of neap tide

During the forth experiment(on September 7, 1981), a remarkable feature was revealed. Considering the current direction from the Table 2, dye patch should have been moved southward in this case. But, it was transported northward as shown in Fig. 3-d. It can be explained from the fact that the net effect by an advection of ocean current of 0~7*cm/sec* is smaller than that of drift by southwesterly wind of 3*m/sec*.

Apparent diffusivity was $3.4\times10^2 cm^2/sec$ at the diffusion time 60 minutes. This figure is much small compared to the previous investigations(Ro: 1980, Kim: 1981). The average elongation rate was about 0.43.

Regression equations of diffusion are

$\ln K_a=5.2228+0.0275t$ (4): during the ebb of spring tide,

$\ln K_a=5.2064+0.0278t$ (5): during the flood of spring tide,

$\ln K_a=3.8344+0.0288t$ (6): during the flood of neap tide,

$\ln K_a=3.9726+0.0384t$ (7): during the ebb of neap tide, here the units of K_a and t are cm^2/sec and minute.

These results in the Jinhae bay suggest that the apparent diffusivity in early stage is small compared to the previous investigation in Kori, but its rate of increase with time is a little larger than that in Kori(Han and Yoon: 1970).

Peak concentrations during neap tides were decreased more rapidly than those during spring tides, as shown in Fig. 4.

Temporal variation of horizontal variance is shown in Fig. 5. It can be easily noticed that the patterns of their temporal variation during ebb and flood of spring tides are similar, and those during ebb of neap tide is increased more rapidly with time than any other time. Okubo

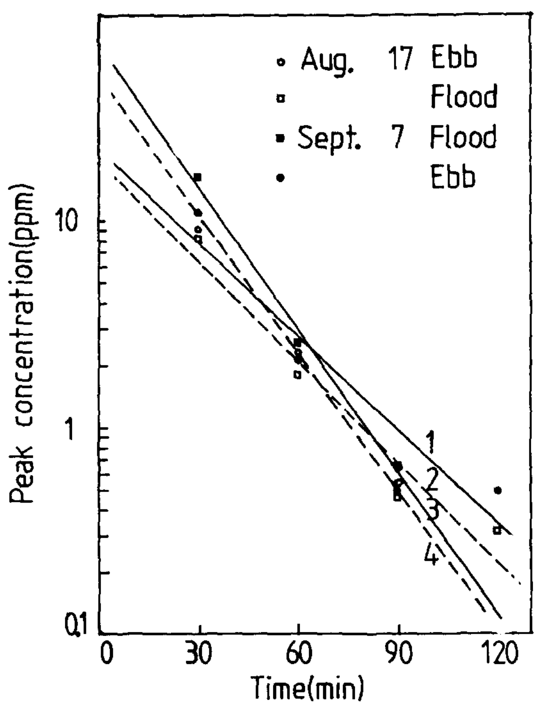

Fig. 4 Peak concentration vs time

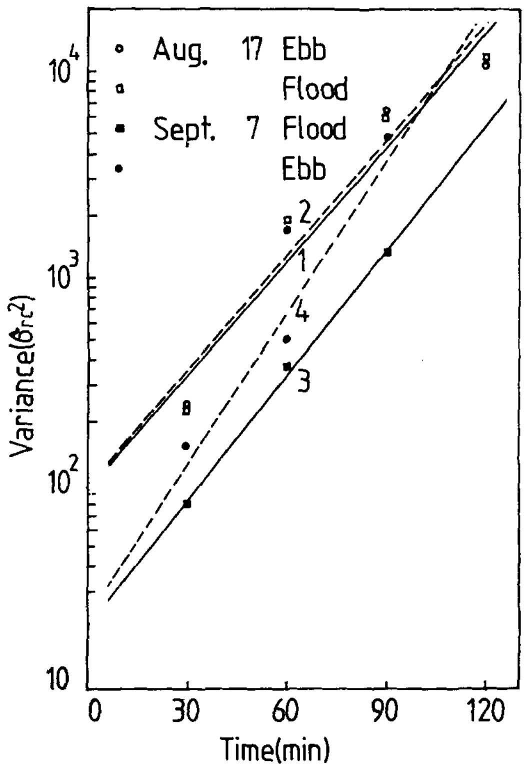

Fig. 5 Variance vs time.

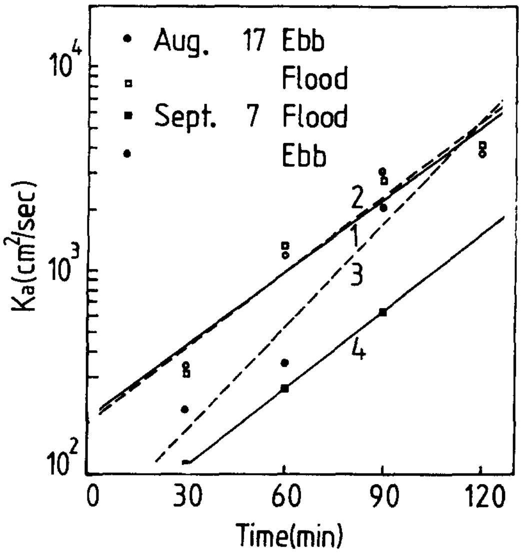

Fig. 6 Diffusion coefficient vs time.

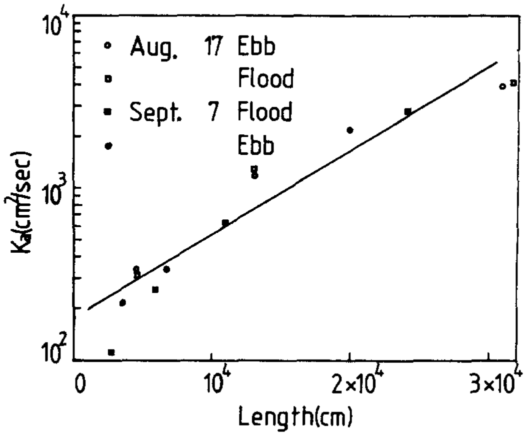

Fig. 7 Diffusion coefficient vs length.

(1971) showed the relation between diffusion time and horizontal variance as $\sigma_{r\beta}^2=kt^3$. But, the results of these experiments do not agree to the formula derived by Okubo. It is considered that the scales of water movement were very small because the experimental sea area was located in a inner bay.

The relations between diffusion coefficient and diffusion time, and those between diffusion time and diffusion length are respectively shown in Fig. 6 and 7.

Through four experiments, following features are revealed: decrease rates of peak concentration during neap tides are larger than those during spring tides, while diffusion coefficients during spring tides are larger than those during neap tides. It is considered that dye patch during neap tides diffuses more uniformly than that during spring tides. But peak concentration during neap tides is larger than that during spring tides.

Conclusion

From the study on oceanic diffusion charactericsis in the Jinhae bay, the following results were obtained.

1) The apparent diffusivities during ebb and flood of spring tides were respectively $3.0\times10^3 cm^2/sec$ and $2.8\times10^3 cm^2/sec$, and those of neap tides were $2.1\times10^2 cm^2/sec$ and $6.2\times10^2 cm^2/sec$, respectively.

2) The regression equations between diffusion time and diffusion coefficient were,

$\ln K_a=5.2228+0.0275t$: during the ebb of spring tide,

$\ln K_a=5.2064+0.0278t$: during the flood of spring tide,

$\ln K_a=3.8344+0.0288t$: during the flood of neap tide,

$\ln K_a=3.9726+0.0384t$: during the ebb of neap tide.

3) The decrease rates of peak concentration during neap tides were larger than those during spring tides. and diffusion coefficent during neap tides were smaller than those during spring tides.

4) Temporal variation of horizontal variance during ebb and flood of spring tides was similar, and that during ebb of neap tide was increaced most rapidly of any other time. The relation between diffusion coefficient and

diffusion time and that between horizontal variance and diffusion time are similar.

5) The increase rate of diffusion coefficient with diffusion length during ebb flow was larger than that during flood flow.

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鎭海灣의 海洋擴散特性硏究

安有信 · 金榮燮 · 韓英鎬

鎭海灣은 여름철에 적조가 자주 발생하는 해역으로서 우리나라 남해안 중 해양 오염이 가장 문제시되고 있는 해역 중의 하나이다 그러므로 오염된 馬山灣의 해수가 鎭海灣으로 어떻게 유입, 희석되는가를 알아보고, 灣외에서 유입되는 해수의 擴散 이동을 조사하기 위하여 대조(1981년 8월 17일)와 소조(1981년 9월 7일) 각 潮汐에 따라 네 번에 걸쳐 Rhodamine B (중량비 6%) 擴散實驗을 실시하였다.

그 결과 대조 때 방출 90분 후의 썰물과 밀물 때의 확산계수는 각각 $3.0\times10^3 cm^2/sec$, $2.8\times10^3 cm^2/sec$이고 소조 때 방출 90분후의 확산 계수는 밀물 때는 $6.2\times10^2 cm^2/sec$, 썰물 때는 $2.1\times10^3 cm^2/sec$로서 소조 때보다 대조 때 더 크게 나타났으며, 다른 해역과 비교해 보면 수영만의 $8.2\times10^2 cm^2/sec$, $1.12\times10^3 cm^2/sec$(Kim: 1981)와 그 값이 거의 비슷하나, 고리에서의 $10^3\sim10^4 cm^2/sec$(Ro: 1980)보다는 매우 적게 나타났다.

鎭海灣 및 馬山灣의 경우, 灣 입구가 협소하고 남쪽으로 열려있어서 여름철에 남풍계열의 바람이 강하게 불면 썰물 때라도 표층수가 역류하여 만으로 들어오기 때문에, 특히 소조 때에는 오염물질의 분산이 잘 되지않고 누적될 가능성이 크게 보인다.