NEAR-FIELD DILUTION OF ROSETTE TYPE MULTIPORT WASTEWATER DIFFUSERS

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Abstract: In this paper, mixing characteristics and dilution of the merging buoyant discharges from array of multiple jets has been extensively studied in the hydraulic model experiments. New equations for dilution, which include the merging effects correctly, were derived. Experiments were constructed in a 20-m long, 4.9-m wide and 0.6-m deep flume, and the model diffuser was manufactured to indicate the typical characteristics of the existing ocean wastewater outfall in South Korea. Buoyant discharge from the diffuser was reproduced using heated water. Water temperature was measured using CC-Type thermocouple sensors, which were connected to a 40-channel data logger.

Experimental results show that merging between ports in a particular riser is dependent upon the discharge densimetric Froude number, whereas merging between two ports which are facing each other at 90° at the adjacent risers is dependent upon the discharge densimetric Froude number and distance from the port and port spacing. Centerline dilution increase with distance from the port outlet until two plumes has merged. However, after merging occurs, increase of the centerline dilution almost stops. Further distance from the position where merging occurs, centerline dilution increases again.

Key Words: Rosette Type Diffuser, Buoyant jet, Dilution, Merging, Experiments

1. INTRODUCTION

One of the effective and economical ways to reduce harmful impact of sewage on the ocean is to use well-designed diffuser structure for ocean wastewater outfall. Optimally designed ocean outfall to discharge suitably treated sewage is required for rapid dilution of the wastewater. In recent years, wastewater multiport diffuser that used riser has been constructed. The risers have 4, 6, or 8 ports at the end, so it is called rosette type diffuser. Most of the wastewater diffusers were built in deep water. However in Korea, Rosette type alternating diffuser has been constructed at relatively shallow water between 6 m and 30 m. Details of wastewater ocean outfall in Korea are summarized in the Table 1 and Fig. 1. The research regarding the Rosette type alternating diffuser has not been carried out so far. As discharge condition and ambient condition were varied, the mixing behavior of rosette type multiport diffuser changes significantly.

The object of this study is to investigate the merging characteristics of rosette type multiport diffuser. In this paper, mixing characteristics and the merging behavior of multiple jets both in still water and flowing ambient have been extensively studied through the hydraulic model experiments.

2. THEORETICAL BACKGROUNDS

2.1 Dilution

The major factors that can determine the dilution of buoyant jets are momentum flux, buoyancy flux, and volume flux. If the buoyant jet discharged in to the flowing ambient, the velocity of ambient flow is also important factor. Thus dilution can be defined as

$$\Phi = f(M_0, J_0, Q_0, u_a, x, y, z) \tag{1}$$

where $M_0 = (\pi/4)d^2U_0^2$= initial momentum flux, $J_0 = (\pi/4)g(\Delta\rho_0/\rho_0)d^2U_0$= initial buoyancy flux, $Q_0 = (\pi/4)d^2U_0$= initial volume flux, u_a = the velocity of ambient flow, x, y = horizontal distance, z = vertical distance.

From dimensional analysis, the Eq. (1) can be presented non-dimensional groups as follows;

$$\Phi = f\left(\frac{J_0^{1/2}Q_0}{M_0^{5/4}}, \frac{M_0^{1/4}u_a}{J_0^{1/2}}, \frac{J_0^{1/2}x}{M_0^{3/4}}, \frac{J_0^{1/2}y}{M_0^{3/4}}, \frac{J_0^{1/2}z}{M_0^{3/4}}\right) \tag{2}$$

The Dilution define the density difference to the initial discharged density at any position, and replacing the density difference to excessive temperature difference, the dilution can be presented as follows;

$$S = \frac{\rho_a - \rho_0}{\rho_a - \rho} = \frac{T_a - T_0}{T_a - T} = \frac{\Delta T_0}{\Delta T} \tag{3}$$

where T_a = temperature of ambient, T_0 = initial discharged temperature

From the relationship of the Eq. (2), the non-dimensional groups can be presented several length scales suggested by Wright (1977, 1984). Thus the dilution can be represented as follows;

$$S = f\left(\frac{L_Q}{L_M}, \frac{L_m}{L_b}, \frac{x}{L_M}, \frac{y}{L_M}, \frac{z}{L_M}\right) \tag{4}$$

where $L_M = M_0^{3/4}/J_0^{1/2}$, $L_Q = Q_0/M_0^{1/2}$, $L_m = M_0^{1/2}/u_a$, $L_b = J_0/u_a^3$.

From the relation of Eq. (4), if the vertical distance z set as water depth h, the surface minimum dilution has the relation as follows;

$$\frac{S_m L_Q}{L_M} = f\left(\frac{L_m}{L_b}, \frac{h}{L_M}\right) \tag{5}$$

Assuming that the Eq. (5) has power relation, the surface minimum dilution can be presented as follows;

$$\frac{S_m L_Q}{L_M} = \alpha\left(\frac{L_m}{L_b}\right)^{\beta}\left(\frac{h}{L_M}\right)^{\gamma} \tag{6}$$

where α, β, γ are constants determined from the experimental data.

In the case of still water condition, the centerline dilution can be obtained by dimensional analysis discarding the current velocity term.

$$\frac{S_c J_0^{1/2} Q_0}{M_0^{5/4}} = f\left(\frac{J_0^{1/2}z}{M_0^{3/4}}\right) = f\left(\frac{z}{L_M}\right) \tag{7}$$

Assuming an power function, the centerline dilution equation can be represented as follows;

$$\frac{S_c J_0^{1/2} Q_0}{M_0^{5/4}} = \xi \left(\frac{z}{L_M} \right)^{\eta} \tag{8}$$

or

$$\frac{S_c}{F_j} = \xi_1 \left(\frac{z}{d \cdot F_j} \right)^{\eta_1} \tag{9}$$

where ξ, η and ξ_1, η_1 are constants determined from the experimental data. F_j is the discharge densimetric Froude number which is defined as $F_j = U_0/(g'd)^{1/2}$, where $g' = g(\Delta\rho/\rho) =$ effective gravitational acceleration, $\Delta\rho =$ density difference between effluence and Ambient, $\rho =$ effluent density.

The two extremities of the buoyant jet are simple jet and simple plume. Thus considering the two cases, dilution relation of buoyant jet can be presumed. In pure jet, as the effect of buoyancy can be negligible, the relation of Eq. (8) has the exponent of 1. While in the case of pure plume, the effect of momentum can be negligible, and the exponent is 5/3. Therefore the buoyant jet may have the exponent value between 1 and 5/3.

2.2 Merging Mechanics of the Rosette Type Multiport diffuser

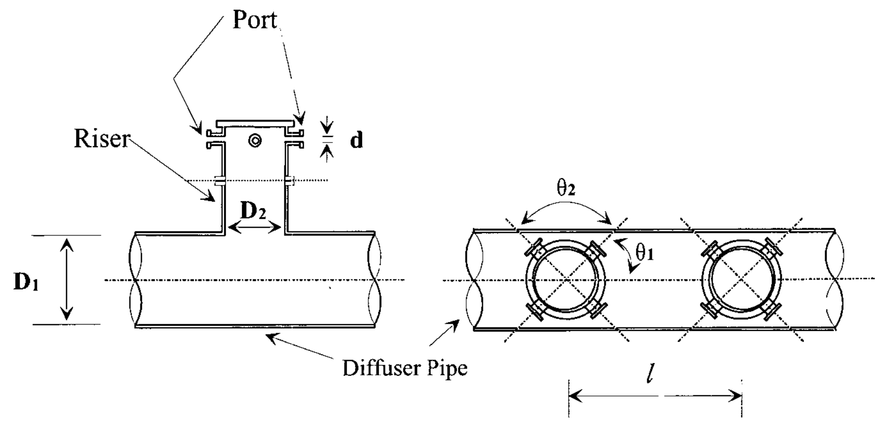
The merging between the ports dominates the behavior of multiple jet. One of the most important factors that affect the merging behavior of buoyant jets, especially rosette type multiport diffuser, is the densimetric Froude number. The densimetric Froude number shows the relative effect between buoyancy and discharge momentum. Given riser space, for a low densimetric Froude number, merging occurs between adjacent ports in each riser. While for a high densimetric Froude number, merging occurs between ports facing each other from adjacent risers. The Fig. 2 shows merging processes of the Rosette type multiport diffuser discharged in still water.

The Rosette type multiport diffuser discharged in ambient flow has very complex merging mechanics. This complex merging process can be divided three type of merging as shown in Fig. 3. The first type is the merging between the ports of oblique counter flow. The second type is the merging between the ports of oblique co-flow. And the third type is the merging between the port of oblique counter flow and the oblique co-flow. In the case of the first and second type merging, the effluents go ahead to the direction of 45° from the diffuser axis. And the distance depends on the relative dominance of initial momentum, buoyancy and ambient flow. The each cross-section of the buoyant jets is expanded to entrain the ambient waster, and simultaneously the trajectories of the buoyant jets are deflected by ambient flow. In the case of the third type merging, the merging height depends on the relative dominance of buoyancy deficiency and flowing ambient.

For the analysis of merging behavior of Rosette type multiport diffuser in the ambient flow, the additional factor of the riser spacing is necessary. The complete merging point is defined as the distance to the ambient flow direction at which the merging between the risers was completed. The complete merging point depends on the velocity ratio, densimetric Froude number and the spacing between the risers. The complete merging point of multiport diffuser has the relation as follows;

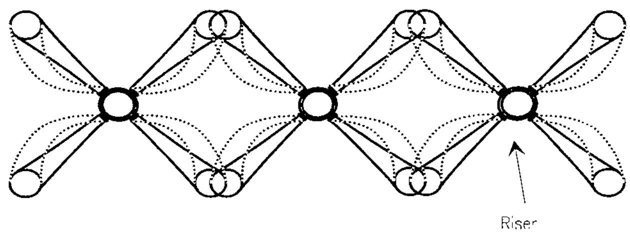
$$\Phi = f(M_0, J_0, Q_0, u_a, x, l) \tag{10}$$

where u_a = the velocity of ambient flow, $x =$ horizontal distance to the ambient flow direction from the diffuser axis, $l =$ spacing between the

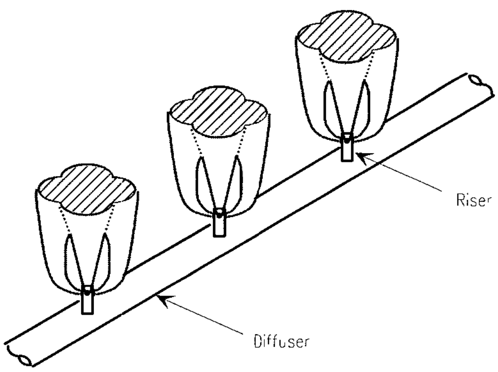


(a) Side View (b) Plan View

Fig. 1. Schematics of the Rosette Type Multiport Diffuser



(a) Merging Between Plumes Discharged from Ports of the Adjacent



(b) Merging of Plumes Discharged from Ports of the Each Riser

Fig. 2. Merging Processes of the Rosette Type Multiport Diffuser

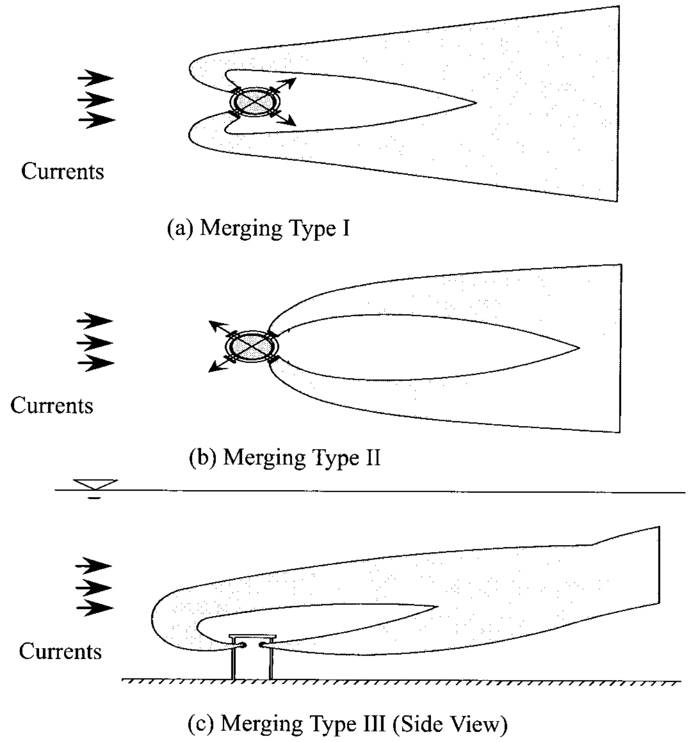


Fig. 3. The merging Types of the Rosette Multiport Diffuser

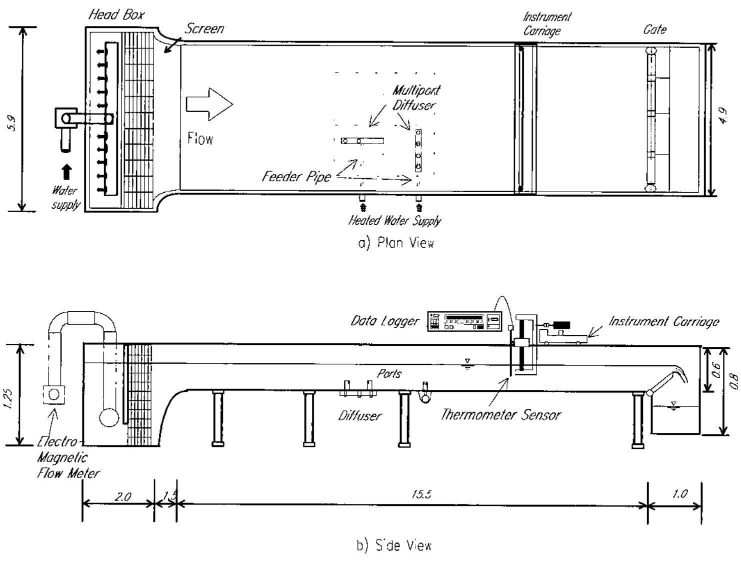


Fig. 4. Experimental Setup (Unit: m)

Table 1. Details of the Domestic Wastewater Sea Outfalls

Outfall		Masan /Changwon	Onsan	Youngyeon	Noksan	Sockcho
Operating Year		1993	1997	1995	-	1999
Depth (m)		13.0	27.0	25.0-27.0	6.5	10-11.5
Design Discharge (m^3/s)		8.23	1.74	4.05	8.24	1.22
Pipe	Dia.(m)	2.00	1.80	2.20	2.50	1.50
	Length(m)	680	2050	3240	182	435
Diffuser	Dia.(m) (D_1)	2.00	1.80	1.80	2.20	0.60
	Length(m)	210	160	470 (156+157+157)	45	50 (25+25)
Riser	Dia.(m) (D_2)	1.35	1.35	1.35	1.20	0.60
	Spacing (m)	10.0	18.0	10.0	9.0	10.0
	No.	21	9	48	6	6
Port	Dia.(m) (d)	0.200	0.250	0.110, 0.120, 0.125	0.500	0.225, 0.250
	No.	80	18	192 (64+64+64)	24	24 (12+12)
Angle (θ_1, θ_2)		120°, 30°	90°, 45°	90°, 45°	90°, 45°	90°, 45°

Table 2. Important Features of Ocean Outfalls in South Korea

Non-Dimensional Term	Masan/Changwon	Noksan	Sokcho
h/d	65	13	44-46
l/d	50	18	40-44
F_j	1.47 (design discharge) 4.2 (1995)	5.0 (2001)	4.4 (2011) 2.8 (1996)
k (u_a/U_0)	0.01-0.05 0.01-0. (design discharge) 0.04-0.17 (1995)	0.06-0.33 (2011)	0.05-0.15 (2011) 0.08-0.23 (1996)

Table 3. Experimental Conditions of Rosette Type Multiport diffuser in still water (Series F)

Case No.	h cm	U_0 cm / s	g'_0 cm / s^2	J_0 cm^4/s^3	M_0 cm^4/s^2	l_M cm	h/d	F_j
F101	45.45	2.19	13.11	23	4	0.57	45.45	0.60
F102	45.45	4.15	16.56	54	14	0.96	45.45	1.02
F103	45.65	6.40	17.85	90	32	1.43	45.65	1.51
F104	45.45	12.59	18.96	187	124	2.72	45.45	2.89
F105	45.45	18.63	19.35	283	273	3.99	45.45	4.23
F106	45.45	24.42	19.47	373	468	5.21	45.45	5.53

F107	45.45	30.90	19.67	477	750	6.56	45.45	6.97
F108	45.45	34.19	19.78	531	918	7.24	45.45	7.69
F109	45.45	43.87	19.90	686	1510	9.26	45.45	9.83
F201	35.05	3.06	16.65	40	7	0.71	35.05	0.75
F202	35.05	9.02	18.57	132	64	1.97	35.05	2.09
F203	35.05	9.00	18.31	129	64	1.98	35.05	2.10
F204	35.05	16.82	19.08	252	222	3.62	35.05	3.85
F205	35.05	19.69	19.16	296	305	4.24	35.05	4.50
F206	35.05	24.76	19.42	378	481	5.29	35.05	5.62
F207	35.05	29.36	19.60	452	677	6.24	35.05	6.63
F208	35.05	37.89	19.78	589	1130	8.02	35.05	8.52
F209	35.05	60.06	20.22	954	2830	12.57	35.05	13.36
F210	35.05	79.39	19.12	1190	4950	17.09	35.05	18.15

Table 4. Experimental Conditions of Rosette Type Multiport diffuser in still water (Series H)

Case No.	h cm	U_0 cm / s	g'_0 cm / s^2	J_0 cm^4 / s^3	M_0 cm^4 / s^2	l_M cm	h/d	F_l
H101	43.75	17.95	19.58	276	253	3.82	43.75	4.06
H102	20.45	17.91	19.65	276	252	3.80	20.45	4.04
H103	15.75	17.82	19.39	272	250	3.81	15.75	4.05
H104	11.05	18.13	19.31	275	258	3.88	11.05	4.13
H105	41.55	16.81	19.55	258	222	3.58	41.55	3.80
H106	39.45	17.82	19.58	274	249	3.79	39.45	4.03
H107	36.45	17.58	19.54	270	243	3.74	36.45	3.98
H108	34.25	18.01	19.85	281	255	3.80	34.25	4.04
H109	31.85	17.32	19.78	269	236	3.67	31.85	3.89
H110	28.45	17.77	19.84	277	248	3.75	28.45	3.99
H111	25.45	14.88	19.56	229	174	3.17	25.45	3.36
H112	22.95	17.86	19.31	271	250	3.83	22.95	4.06
H113	46.65	18.17	19.49	278	259	3.87	46.65	4.12
H114	35.75	18.02	19.59	277	255	3.83	35.75	4.07
H115	33.95	17.89	19.40	273	251	3.82	33.95	4.06
H116	39.35	17.81	19.38	271	249	3.81	39.35	4.05
H201	40.45	12.95	19.06	194	132	2.79	40.45	2.97
H202	12.85	13.29	19.24	201	139	2.85	12.85	3.03
H203	8.15	12.80	19.30	194	129	2.74	8.15	2.91
H204	36.25	13.16	19.21	199	136	2.83	36.25	3.00
H205	30.35	12.72	19.27	192	127	2.73	30.35	2.90
H206	25.45	14.64	19.10	220	168	3.15	25.45	3.35
H207	20.55	13.70	19.22	207	147	2.94	20.55	3.12
H208	15.45	13.93	19.33	211	152	2.98	15.45	3.17
H209	10.45	13.49	19.18	203	143	2.90	10.45	3.08
H210	17.95	14.41	18.95	215	163	3.12	17.95	3.31
H211	22.95	14.45	19.15	217	164	3.11	22.95	3.30

H212	25.35	13.59	19.12	204	145	2.93	25.35	3.11
H213	18.15	12.87	19.11	193	130	2.77	18.15	2.94
H214	46.75	14.38	19.06	215	162	3.10	46.75	3.29

Table 5. Experimental Conditions of Rosette Type Multiport diffuser in still water (Series T)

Case No.	h cm	U_0 cm / s	$g'0$ cm/ s^2	J_0 cm^4 / s^3	M_0 cm^4 / s^2	l_M cm	h/d	F_i
T101	25.9	3.99	18.28	57	13	0.88	25.9	0.93
T102	35.45	4.84	17.58	67	18	1.09	35.45	1.15
T103	35.45	4.87	16.87	65	19	1.12	35.45	1.19
T104	45.45	5.66	18.08	80	25	1.25	45.45	1.33
T105	35.45	9.58	18.79	141	72	2.08	35.45	2.21
T106	35.45	16.98	19.57	261	226	3.61	35.45	3.84
T107	25.90	17.35	20.21	275	236	3.63	25.90	3.86
T108	35.45	17.88	20.98	295	251	3.67	35.45	3.90
T109	25.45	17.66	19.22	267	245	3.79	25.45	4.03
T110	35.45	19.09	19.59	294	286	4.06	35.45	4.31
T111	35.45	21.22	19.79	330	354	4.49	35.45	4.77
T112	35.45	26.05	20.08	411	533	5.47	35.45	5.81
T113	35.45	26.02	19.89	407	532	5.49	35.45	5.83
T114	35.45	33.96	20.31	542	906	7.10	35.45	7.54
T115	35.45	34.16	20.32	545	916	7.13	35.45	7.58
T116	45.45	33.59	19.60	517	886	7.14	45.45	7.59
T117	45.45	33.82	19.60	521	898	7.19	45.45	7.64

Table 6. Experimental Conditions of Rosette Type Multiport diffuser in Ambient Current (l/d=40)

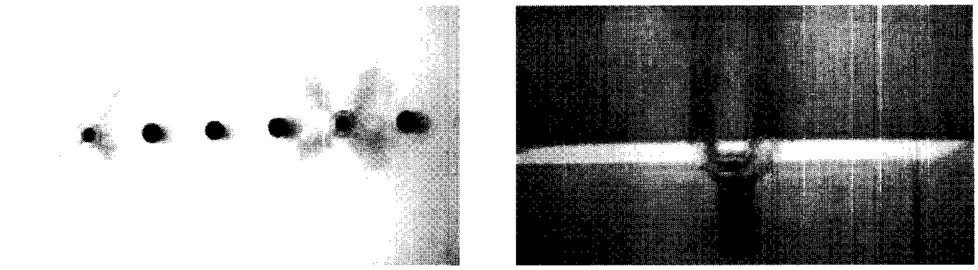
Case No.	h cm	U_0 cm/s	u_a cm/s	g'_0 cm/s^2	J_0 cm^4/s^3	M_0 cm^4/s^2	L_M cm	L_m cm	L_b cm	h/d	F_i	k	F_a
C101	30.4	8.18	2.02	13.06	83.93	52.57	2.13	3.60	10.24	30.4	2.26	0.25	0.65
C102	30.6	5.93	1.90	13.10	61.04	27.65	1.54	2.77	8.88	30.6	1.64	0.32	0.75
C103	30.7	3.25	1.58	12.28	31.32	8.29	0.87	1.83	7.98	30.7	0.93	0.49	0.84
C104	30.3	3.23	1.75	12.75	32.38	8.22	0.85	1.64	6.03	30.3	0.91	0.54	1.11
C105	30.7	6.35	4.14	12.71	63.45	31.71	1.68	1.36	0.89	30.7	1.78	0.65	7.46
C106	30.8	6.49	4.30	13.35	68.00	33.05	1.67	1.34	0.86	30.8	1.78	0.66	7.79
C107	30.6	3.22	3.43	11.95	30.23	8.14	0.88	0.83	0.75	30.6	0.93	1.06	8.87
C108	30.8	3.23	3.72	12.80	32.44	8.18	0.85	0.77	0.63	30.8	0.90	1.15	10.59
C109	25.7	2.83	5.83	11.49	25.53	6.29	0.79	0.12	0.13	25.7	0.83	2.06	51.64
C110	25.4	2.74	5.66	12.31	26.51	5.90	0.74	0.12	0.15	25.4	0.78	2.07	45.64

Table 7. Experimental Conditions of Rosette Type Multiport diffuser in Ambient Current (l/d=30)

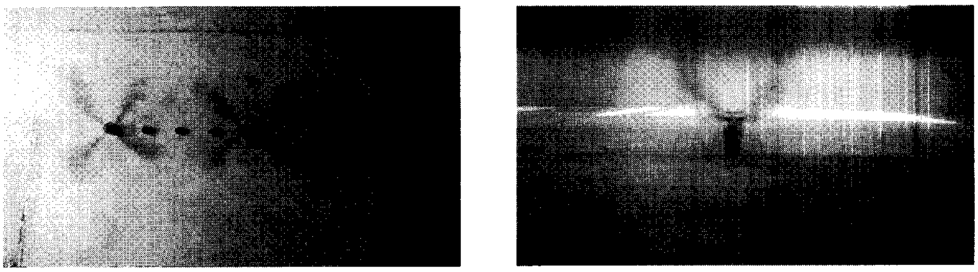
Case No.	h cm	U_0 cm/s	u_a cm/s	g'_0 cm/s^2	J_0 cm^4/s^3	M_0 cm^4/s^2	L_M cm	L_m cm	L_b cm	h/d	F_j	k	F_a
C201	31	7.25	0.62	13.69	77.89	41.25	1.84	0.10	328.35	31	1.96	0.09	0.02
C202	30.8	3.51	0.97	13.12	36.20	9.70	0.91	0.03	39.97	30.8	0.97	0.28	0.14
C203	30.9	4.40	1.33	13.26	45.76	15.17	1.14	0.03	19.55	30.9	1.21	0.30	0.29
C204	30.3	5.17	1.61	13.50	54.85	21.01	1.33	0.03	13.26	30.3	1.41	0.31	0.42
C205	30.2	2.42	1.70	12.79	24.35	4.61	0.64	0.01	5.00	30.2	0.68	0.70	1.13
C206	30.8	4.85	3.94	13.34	50.82	18.48	1.25	0.01	0.83	30.8	1.33	0.81	6.75
C207	30.7	2.34	3.26	12.27	22.59	4.32	0.63	0.01	0.65	30.7	0.67	1.39	8.60
C208	25.3	2.45	6.15	12.81	24.61	4.70	0.64	0.004	0.11	25.3	0.68	2.52	53.20
C109	25.7	2.83	5.83	11.49	25.53	6.29	0.79	0.12	0.13	25.7	0.83	2.06	51.64
C110	25.4	2.74	5.66	12.31	26.51	5.90	0.74	0.12	0.15	25.4	0.78	2.07	45.64

Table 8. Experimental Conditions of Rosette Type Multiport diffuser in Ambient Current (l/d=20)

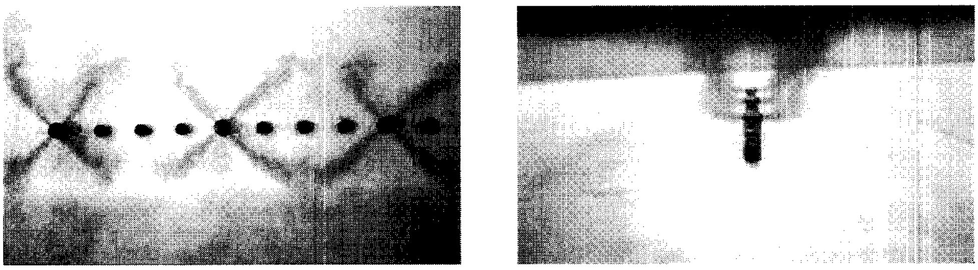
Case No.	h cm	U_0 cm/s	u_a cm/s	g'_0 cm/s^2	J_0 cm^4/s^3	M_0 cm^4/s^2	L_M cm	L_m cm	L_b cm	h/d	F_j	k	F_a
C301	30.8	4.04	1.12	13.18	41.86	12.85	1.05	3.20	29.92	30.8	1.11	0.28	0.13
C302	30.3	3.96	1.52	12.98	40.32	12.29	1.03	2.31	11.48	30.3	1.10	0.38	0.33
C303	30.8	4.28	1.77	12.67	42.64	14.42	1.13	2.15	7.72	30.8	1.20	0.41	0.49
C304	30.5	5.45	2.30	13.10	56.03	23.29	1.42	2.10	4.62	30.5	1.50	0.42	0.81
C305	30.7	4.88	2.18	13.31	51.01	18.71	1.26	1.98	4.92	30.7	1.34	0.45	0.76
C306	30.4	2.45	1.68	12.49	24.02	4.71	0.65	1.29	5.03	30.4	0.69	0.69	0.75
C307	30.3	5.39	5.00	13.07	55.36	22.82	1.40	0.96	0.44	30.3	1.49	0.93	8.47
C308	30.7	3.63	4.40	12.71	36.25	10.36	0.96	0.73	0.43	30.7	1.02	1.21	8.80
C309	30.3	2.45	3.72	12.52	24.08	4.71	0.65	0.58	0.47	30.3	0.69	1.52	8.00
C310	25.8	2.45	6.04	12.71	24.42	4.70	0.65	0.36	0.11	25.8	0.69	2.47	33.90



(a) *F101; h/d = 45.45,* F_j *= 0.6*

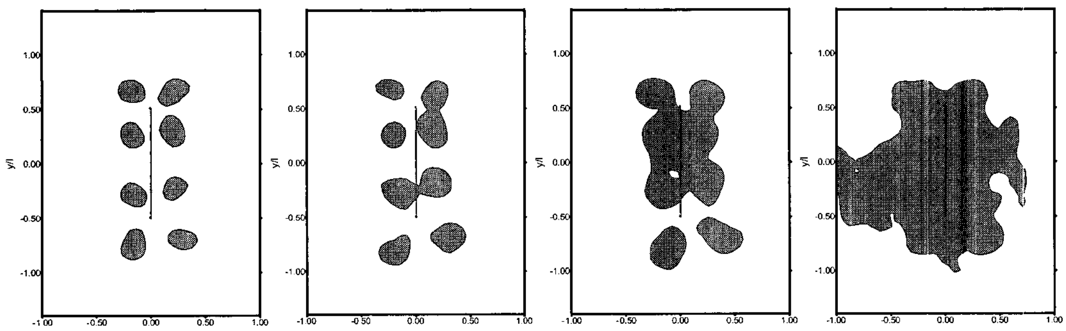


(b) *T107; h/d = 25.9,* F_j *= 3.86*



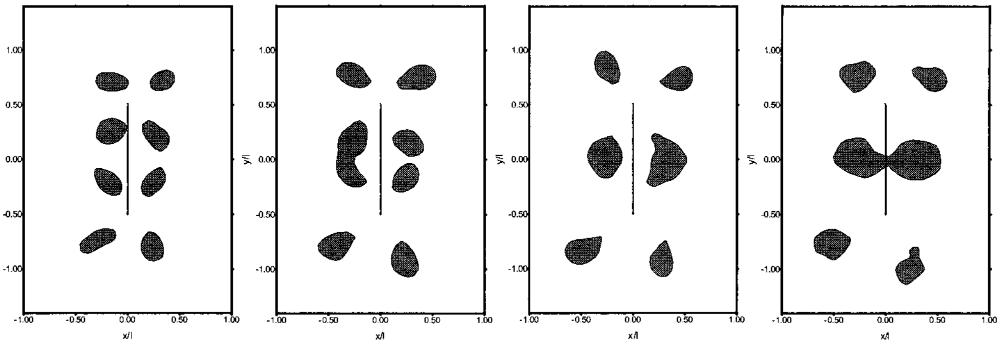
(c) *T109; h/d = 25.45,* F_j *= 4.03*

Fig. 5. The Merging Process of the Rosette Type Diffuser



(a) *z/d=11.1* (b) *z/d=15.1* (c) *z/d=19.1* (d) *Z/d=23.1*

Fig.6. Merging Process at various Depth (T105, F_j**=2.21)**



(a) $z/d= 3.1$ (b) $z/d= 7.1$ (c) $z/d=11.1$ (d) $Z/d=15.1$

Fig.7. Merging Process at various Depth (T111, F_j=4.77)

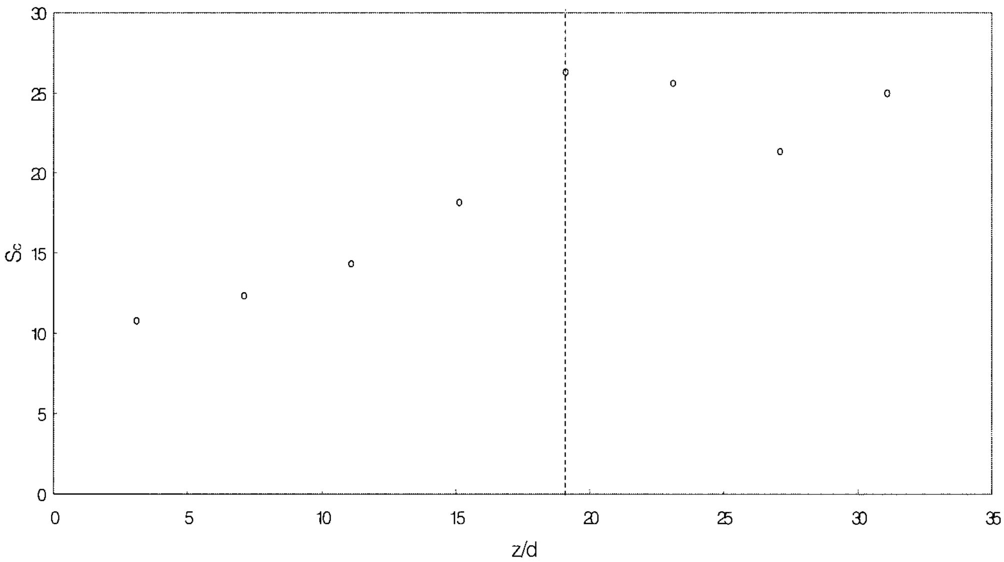


Fig. 8. Centerline Dilution(T105, F_j=2.21)

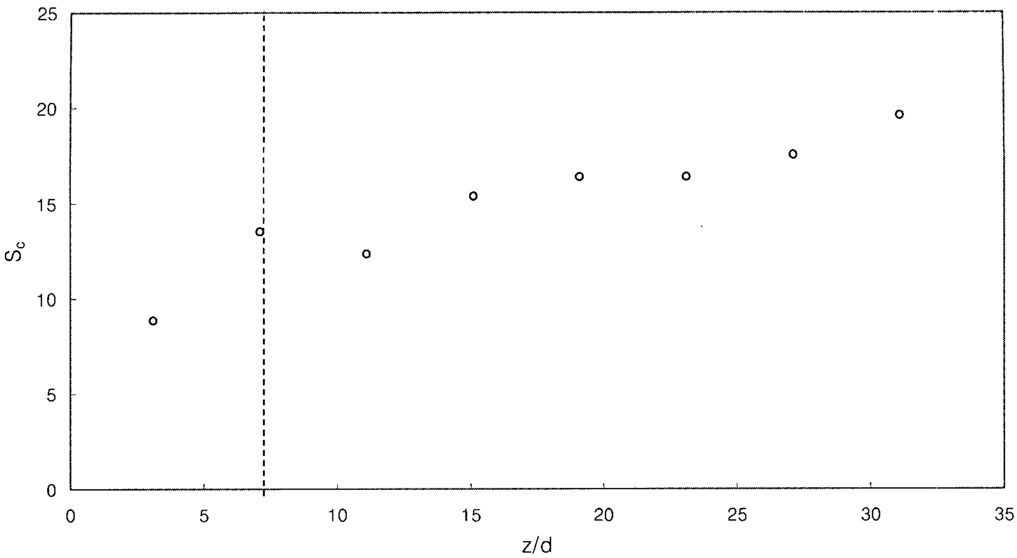


Fig. 9. Centerline Dilution(T111, F_j=4.77)

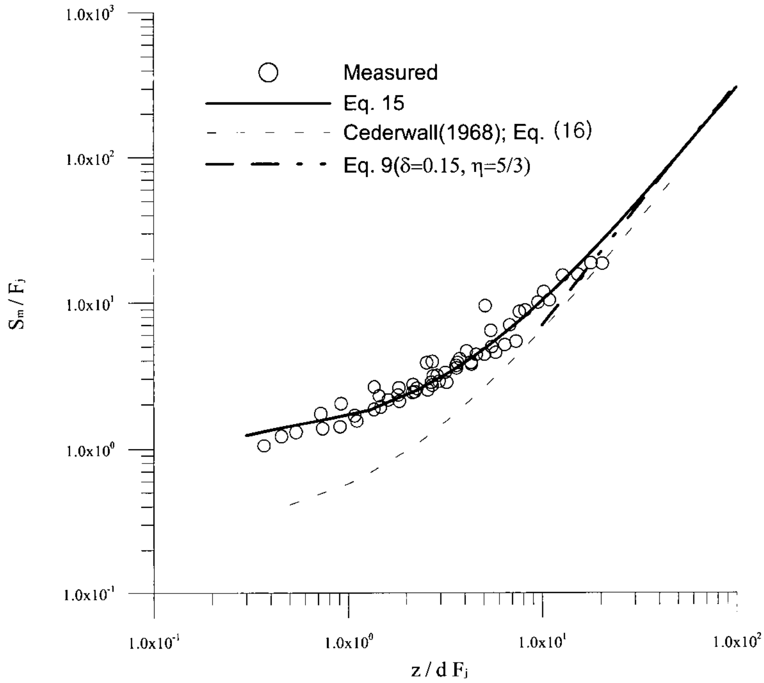
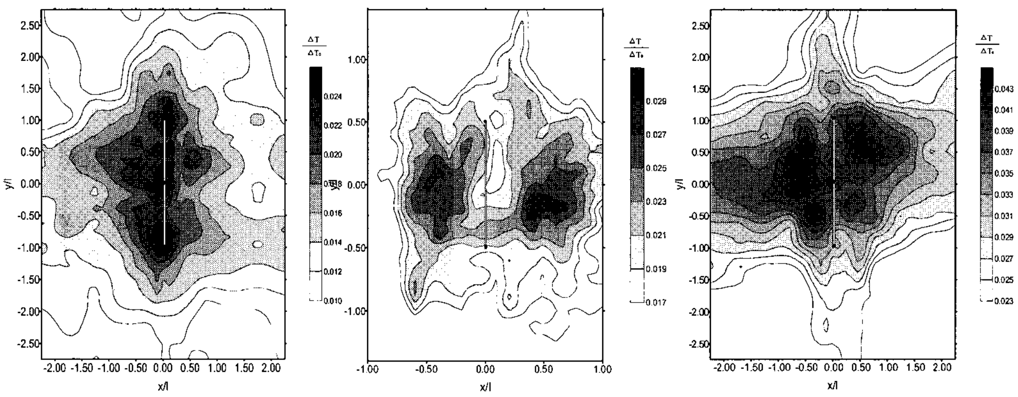


Fig. 10. Centerline Dilution (T series)



(a) $F_j=1.02$ (b) $F_j=5.62$ (c) $F_j=6.97$

Fig. 11. Excess Temperature Distribution at Water Surface

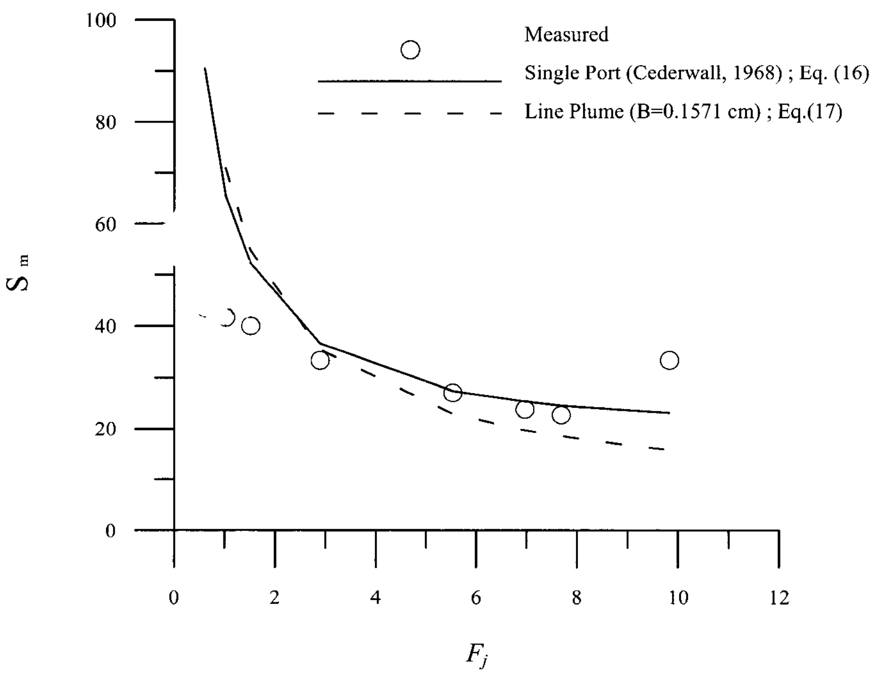


Fig. 12. Surface Minimum Dilution (*z/d=45.5*)

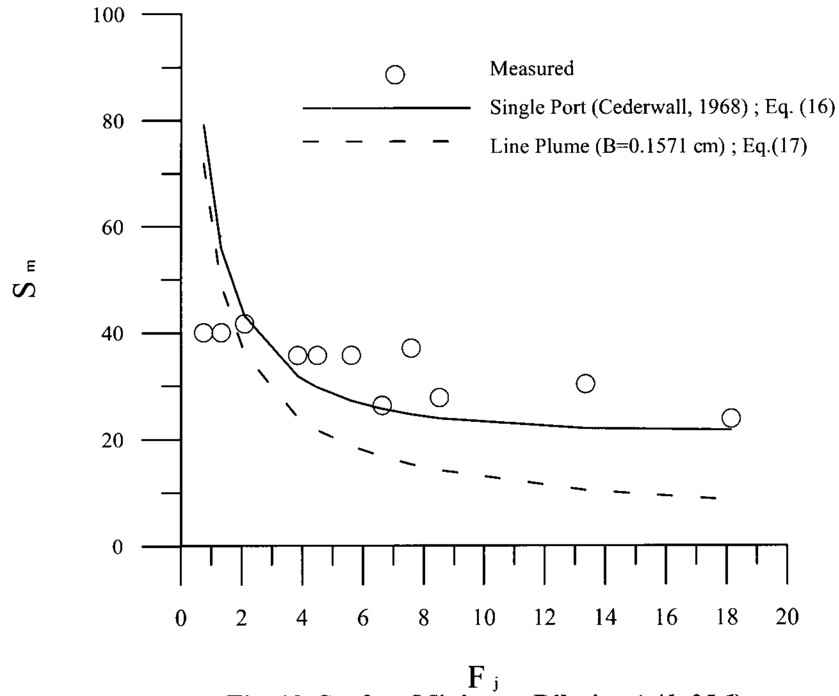


Fig. 13. Surface Minimum Dilution (*z/d=35.1*)

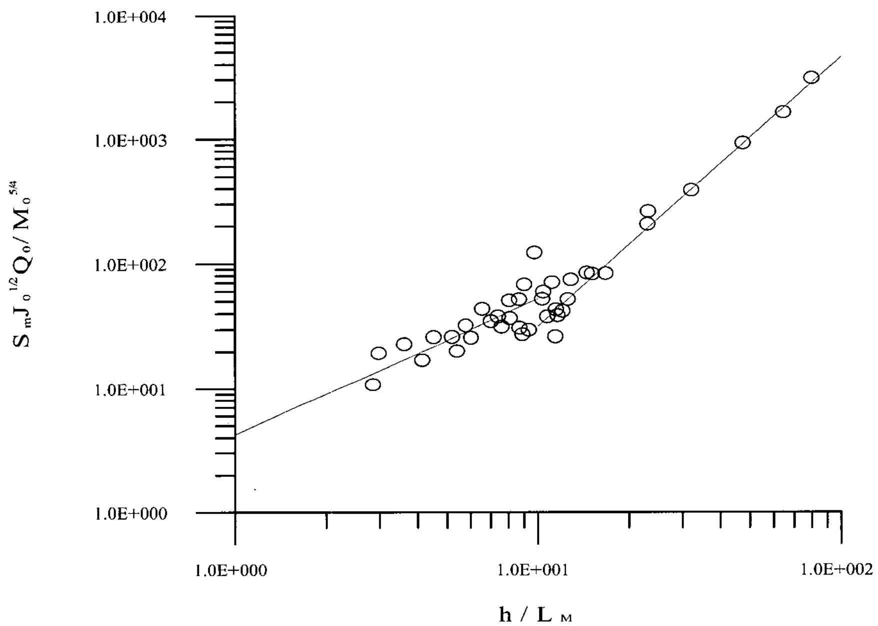


Fig.14. Surface Minimum Dilution of Rosette Type Multidiffuser in Still Water

risers.

From dimensional analysis, the Eq. (10) can be presented using non-dimensional parameters as follows;

$$\frac{x}{L_M} = f\left(\frac{L_Q}{L_M}, \frac{L_m}{L_b}, \frac{l}{L_M}\right) \quad (11)$$

where, $L_m = M_0^{1/2}/u_a$, $L_b = J_0/u_a^3$.

If we assume that the relation of Eq. (11) is power function, the Eq. (11) can be presented as follows;

$$\frac{x}{L_M} = \alpha_1\left(\frac{L_Q}{L_M}\right)^{\beta_1}\left(\frac{L_m}{L_b}\right)^{\gamma_1}\left(\frac{l}{L_M}\right)^{\delta_1} \quad (12)$$

where $\alpha_1, \beta_1, \gamma_1, \delta_1$ are constants determined from the experimental data.

3. EXPERIMENTS

3.1 Experimental Apparatus and Measuring Equipment

Laboratory model was constructed in a 20-m long, 4.9-m wide and 0.6-m deep flume in the Hydraulics Laboratory at Seoul National University, Seoul, Korea. A schematic diagram of the laboratory flume and the experimental setup is shown in Fig. 4. The model diffuser, analyzing geometry of diffusers and conditions of swage water discharged from sea outfall presently, is manufactured to indicate the representative characteristics. Total length of the model diffuser, L_D, is 120 cm. The inner diameter of the port is 1.0 cm and with spacing of l/d = 20, 30, 40. The angle between the port and the diffuser axis is selected to be 45°.

Flow rates were measured using an electro-magnetic flow meter. Density deficiency represents as temperature difference between ambient and warm effluent. Water temperature was measured using CC-Type thermocouple sensors, installed on the instrument carriage. Thermocouple sensors are connected to a 40-channel data logger in whom measured temperatures are stored in digital form. The effluent was supplied from a specially manufactured hot water bath, which consisted of a preheating bath and constant head tank that provided hot water of a constant temperature and flow rate. The discharge from the constant head tank to the diffuser pipe was measured using an electro-magnetic flow meter.

3.2 Experimental Conditions

In this study, experimental conditions were selected to approximately represent domestic ocean outfall conditions. The relevant features of domestic outfalls are listed in Table 2. In this table, h means the water depth. The relation between model and prototype can be determined by densimetric Froude similarity rule as follow;

$$F_{jr} = \frac{U_{0r}}{(g'_r d_r)^{1/2}} = 1 \quad (13)$$

where, $U_{0r} = U_{0m}/U_{0p}$ = effluent velocity of the model/ effluent velocity of the prototype, $g'_r = g'_m/g'_p$ = effective gravitational acceleration of the model/ effective gravitational acceleration of the prototype, $d_r = d_m/d_p$ = port diameter of the model/ port diameter of the prototype.

Experimental conditions for still water experiments are listed in Tables 3-5, and experimental conditions for flowing ambient cases are given in Tables 6-8.

4. ANALYSIS OF EXPERIMENTAL RESULTS

4.1 Still Water Characteristics

The Fig. 5 shows the typical merging process of the Rosette type multiport diffuser horizontally discharged in still water. The Fig. 5 (a) is the case of low densimetric Froude number and shows the merging in a riser. Here, effluents from the riser immediately go upward and merged with each other. The higter the densimetric Froude number is, the longer the horizontal distance of the effluents is. And the merging between the risers is shown in Fig. 5 (b) and (c). these different types of merging process are also depicted in Figs. 6-7. In these figures, boundaries of the cross sections are defined by half width at which concentration is 1/e of the centerline concentration. The Figs. 8 - 9 are the measured centerline dilution corresponding to Figs. 6 - 7. These figures clearly show the merging effect to the centerline dilution. In Figs. 6 and 8, it is found that merge occurs at $z/d=19.1$. Thus above this point increasing rate of centerline dilution reduces sharply as dshown in Fig. 8. This fact is also found in Figs. 7 and 9, in this case, merge occurs at $z/d=7.1$.

The measured data of centerline dilution are represented in Fig. 10. To explain the trend of the measured data shown in Fig. 10, Eq. (9) is modified as

$$\frac{S_c}{F_j} = \xi_2\left(\frac{C_1 z}{d \cdot F_j} + \zeta\right)^{\eta_2} \tag{14}$$

The coefficients in Eq. (14) are determined form the experimental results as follows;

$$\frac{S_c}{F_j} = 0.62\left(\frac{0.4_1 z}{d \cdot F_j} + 1.40\right)^{5/3} \tag{15}$$

The data obtained in the relatively shallow depth and it retained horizontal momentum effect. In general if $z/dF_j > 10$, the initial momentum effect are negligible. But the data of this study have the range of $z/dF_j = 0.5\text{-}20$. For the increasing of z/dF_j, the Eq. (15) gradually change to the shape of Eq. (9) ($\eta = 5/3$).

The Fig. 11 shows excess temperature at water surface of the typical cases of F series. In the case of lower densimetric Froude number (a), the effluents immediately move upward as like plume and the points of the surface minimum dilution appeared on the diffuser axis. While for the higher densimetric Froude number, the merging between the risers occurred, the positions of surface minimum dilution appeared are apart from the diffuser axis

The experimental results of the variation of surface dilution for the densimetric Froude number and the discharged depth are compared to the general method of Cederwall's equation and line plume equation. In general, before merging the behavior of multiport diffuser is analyzed using single port equation, such as Cederwall's equation Eq. (16), and after merging line plume equations such as Eq. (17) are used.

$$S_c = 0.54F_j\left(\frac{z}{d \cdot F_j}\right)^{7/16} \quad \text{for} \quad \frac{z}{d} < 0.5F_j \tag{16a}$$

$$S_c = 0.54F_j\left(\frac{0.38z}{d \cdot F_j} + 0.66\right)^{5/3} \quad \text{for} \quad \frac{z}{d} \geq 0.5F_j \tag{16b}$$

$$S = 0.36g'^{1/3}\, d / q^{2/3} \tag{17}$$

where q is the initial discharge per unit length. Figs. 12 and 13 show the variation of surface minimum dilution for various densimetric

Froude number. For the cases of lower densimetric Froude number (F_j<2), the equations show a steep decreasing of dilution, whereas the measured data show a gradual decreasing.

The experimental data of series F and H was represented in the Fig. 16. As shown in Fig. 16, measured data shows two distinct behavior depending upon the value of h/L_M, fitting Eq. (8) to the measured data, we get

$$\frac{S_c J_0^{1/2} Q_0}{M_0^{5/4}} = 4.26\left(\frac{h}{L_M}\right)^{1.09} \quad \text{for} \quad \frac{h}{L_M} < 10 \tag{18a}$$

$$\frac{S_c J_0^{1/2} Q_0}{M_0^{5/4}} = 0.22\left(\frac{h}{L_M}\right)^{2.16} \quad \text{for} \quad \frac{h}{L_M} > 10 \tag{18b}$$

When the momentum is small, the exponent of this equation is some what different to the theoretical value of plume, 5/3. But the exponent of this equation is very similar to the theoretical value of jet (jet: 1) for the large momentum. This is due to merging characteristics of the Rosette type multiport diffuser, in case of negligible momentum, the effect of dilution is low because of the merging in a riser, whereas the momentum is large, the effect of merging is reduced by the horizontal moving of the buoyant jets.

4.2 Flowing Ambient Characteristics

Fig. 15 shows the typical merging process of the Rosette type multiport diffuser horizontally discharged in flowing ambients. Fig. 15 (a) is the case of low velocity ratio, and this shows a relative week deflection to the current direction with the merging in a riser. Near the surface, the spreading to the up and downstream was found. This phenomenon was also reported by Roberts et al. (1989). From the experiments using T-type diffuser, they reported that the phenomenon occurs in the range of F_a<1. Here F_a is Robert's Froude number, which is defined as (current velocity)^3/(buoyancy flux per unit length of diffuser). The deflection was increases as the velocity ratio increases, as shown in Fig. 15 (b) and (c).

For many cases in ambient flow, the complete merging point was obtained using the isothermal at the cross section that is parallel to the diffuser axis and perpendicular to the current. The isotherms of typical case discharged in to flowing ambient were represented in Fig. 16. At x/l=0.2, the effluents of a risers are merged, however the merging between the risers does not occur yet. At x/l=0.8, the merging between risers is finished. At x/l=2.0, the merged plume rise to the surface. The measured cross sections have some spacing to current direction. If any cross section shows the situation of complete merging, the initial merging point should not be higher than that cross section. Based upon this concept, the equation of the complete merging point was obtained from the experimental results as follows;

$$\frac{x}{L_M} = 0.461\left(\frac{L_Q}{L_M}\right)^{-0.81}\left(\frac{L_m}{L_b}\right)^{0.66}\left(\frac{l}{L_M}\right)^{1.21} \tag{19}$$

or

$$\frac{x}{d} = 0.531 F_j^{1.26} k^{1.32}\left(\frac{l}{d}\right)^{1.21} \tag{20}$$

If the effluents are discharged into the flowing ambient, the dilution at the water surface is affected by the ambient current, initial momentum and buoyancy. Fig. 17 shows the typical cases of the variation of surface temperature distribution for various velocity ratio, riser space, and densimetric Froude number. Fig. 17 (a) is the case of lower velocity ratio; i.e. the effluent velocity is very larger than the current. Because of the small densimetric Froude number, the surface minimum dilution is found near the diffuser axis. While for the case of higher velocity ratio cases as shown in Fig. 17 (b) and (c), the surface minimum dilution is found for from the diffuser axis.

Roberts (1977, 1979) suggested the line plume equations from the plane jet experiments as

$$\frac{S_m q}{u_a h} = 0.27 F_a^{-1/3} \quad \text{for} \quad F_a < 0.1 \qquad (21)$$

$$\frac{S_m q}{u_a h} = 0.58 \quad \text{for} \quad F_a > 0.1 \qquad (22)$$

This line plume analysis and the measured data of this study are represented in Fig. 18. In cases that the effect of current is small, measured data is in good agreement with the line plume analysis results. However, as the ambient current gets higher, the line plume equation tends to overestimate the experimental results.

Fitting Eq. (5) to the measured data of the surface minimum dilution, we get

$$\frac{S_m L_Q}{L_M} = 0.65 \left(\frac{L_m}{L_b} \right)^{1/4} \left(\frac{h}{L_M} \right)^{5/4} \qquad (23)$$

5. CONCLUSIONS

In this study, the merging process of Rosette type multiport diffuser, which is the typical type for the wastewater outfall in Korea, was studied by experimental approach. For the dilutions of buoyant jet in still water and ambient current, equations for dilution were derived from the dimensional analysis and experimental data. The proposed equations are found to be reasonable, and represent the mixing characteristics of the Rosette type diffuser. The experimental results show that merging process of Rosette type multiport diffuser in ambient water is very complex. The equation of complete merging point is proposed to estimate the distance from the diffuser axis to the point at which the merging process was finished. In this study, dilution data at the water surface were compared with the existing analysis. Because of the complete merging behavior of the Rosette type diffuser, it is necessary to be careful for the using of the existing analysis for this diffuser type. In this paper, new equations for analysis for surface minimum dilution for both still water and flowing ambient condition were proposed.

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