TESTING THE CORMIX2 AND VISJET MODELS TO PREDICT THE DILUTION OF SAN FRANCISCO OUTFALL

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ABSTRACT
In recent years using mixing zone models for estimating the initial dilution has received attention from many researches who are interested in design of outfalls for disposal of waste water into coastal areas. In this study the near field dilution of buoyant and non buoyant effluent from outfalls discharging into different environments has been investigated. A group of three outfalls with multi port diffusers have been designed for the discharge of waste water into the Pacific Ocean off the west side of the San Francisco Peninsula. These outfalls are intended to dispose both dry weather (sanitary waste water) and the wet weather (storm and runoff) flows that are collected by San Francisco's combined sewer system. A laboratory plume dilution study was used as an aid in designing the diffusers. A length scale model (CORMIX2) and an integral type model (VISJET) which are programmed for the analysis and prediction of waste water dilution were used to simulate the laboratory experiment. The obtained results indicate that dilution estimated by CORMIX2 and VISJET models are relatively in good agreement with dilution obtained from laboratory data in the unstratified condition. However, CORMIX2 model has some limitation when used for stratified conditions which should be considered.

KEYWORDS: Length scale model, integral type model, numerical simulation, near field dilution, multi port diffuser, CORMIX2, VISJET.

INTRODUCTION
Ocean disposal is an effective method of waste water discharge in the coastal areas. In this method waste water was discharged to the ambient water and dilution mechanism affect on the effluent. Therefore, dilution process can be reduced the adverse impact of waste water disposal on the environment. Discharging through the open end of a submerged pipe is a simple structure of ocean disposal system. Using submerged multi-port diffusers results in much higher initial dilution and reduces the immediate effect of the discharged flow on the ocean. A multi-port diffuser is a linear structure that consists of a manifold containing many closely spaced ports through which wastewater is discharged (Won seo et al., 2001).

Physical model and laboratory experiment are usually conducted to simulate a real case in the nature and to analyze the flow behavior and it's characteristics. In fact, laboratory studies are used to predict and optimize plume dilution. When computers become available the ability to simulate flow behavior and predict their corresponding parameters were greatly increased, numerical simulation such as CORMIX2 and VISJET are firmly established as commons tool to simulate the plume behavior.
Environmental process itself is extremely complex and defies exact simulation. Initial dilution obtained from laboratory experiments and field observations have been extensively verified and compared with numerical simulation models (Tsanis & Valeo, 1994; Valeo & Tsanis, 1996; and Zaker et al., 2001). In these studies, numerical results were in good agreement with laboratory data and field measurement.

In this study a group of three outfalls with multi-port diffusers located near Lake Merced in the San Francisco (Figure1) were simulated by VISJET and CORMIX2 models. VISJET (Lee et al., 2000) uses integral equations for simulation of plume behavior, while CORMIX2 (Akar & Jirka, 1991) is a length scale model.

In these simulations, designs contained clusters of ports and waste water was discharged through 2 to 8 ports per risers. The aim of this study was to compare the performance CORMIX2 and VISJET models when the flow was discharged though clusters of ports.

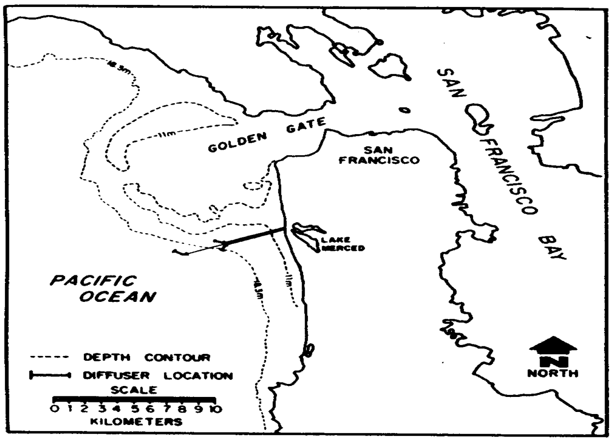

***Figure 1**: Location map and proposed outfall system (after Isaacson et al., 1983)*

GOVERNING EQUATIONS

Plume behavior and dilution are characterized by volume, kinematics momentum and buoyancy fluxes, respectively.

$$Q_{\circ} = \frac{\pi}{4}.d^2.U_{\circ} \tag{1}$$

$$M_{\circ} = U_{\circ}.Q = \frac{\pi}{4}.d^2.U_{\circ}^2 \tag{2}$$

$$B_{\circ} = \frac{\pi}{4}.d^2.U_{\circ}.g_{\circ}^{'} \tag{3}$$

Where d is port diameter, $U_{\circ}$ is discharge velocity and $g_{\circ}^{'}$ is effective gravitational acceleration, can be written:

$$g_{\circ}^{'} = g\left(\frac{\rho_{\circ} - \rho_a}{\rho_a}\right) \tag{4}$$

Where g is gravitational acceleration, $\rho_{\circ}$ is effluence density and ρ_a is ambient density (Fischer et al. 1979). Dimensional analysis of the above parameters, in unstratified condition flow, leads to two length scales definitions (Jirka & Doneker 1991).

$$L_Q = \frac{Q_{\circ}}{M_{\circ}^{1/2}} \tag{5}$$

$$L_M = \frac{M_{\circ}^{3/4}}{B_{\circ}^{1/2}} \tag{6}$$

L_Q is the discharge (geometric) length scale and L_M is the jet /plume transition length scale. When Z is smaller than L_Q the behavior of the plume is unpredictable. For $Z > L_Q$, jet geometry is not important and flow behavior is governed by $M_{\circ}$ and $B_{\circ}$,while for $Z > L_M$ the buoyancy becomes more effective and the flow is plume like. when $Z < L_M$ the initial jet momentum becomes more important than the initial buoyancy momentum and the flow is jet like. To consider the effect of a current to a buoyant plume, another relevant length scale may be defined (Wright, 1977):

$$L_b = \frac{B_{\circ}}{u_a^3} \tag{7}$$

CORMIX uses the above mentioned length scales to classify the flow regime and predict the initial dilution. CORMIX2 is a part of CORMIX used for diffuser design. (Akar & Jirka,1991).

Integral type models are based on ordinary differential equations. These models are able to simulate only the characteristics of the flow near the source. In these models the excess momentum flux can be expressed as:

$$m_e = \int_0^{\infty} u_e(u_e + U_a).2\pi r \ dr \tag{8}$$

where m_e is the excess momentum flux, $u_e = u - U_a$ is the excess velocity and $A_{\circ} = \pi D^2/4$ is the cross sectional area of nozzle. U is the velocity leaving the tube in the turbulent jet. The centerline dilution in co-flow in jet-like condition is expressed as (Chu et al., 1999):

$$S_C = \frac{\lambda^2 \pi B^2 \left(U_a + \frac{2}{1+\lambda^2} \Delta U \right)}{2Q_\circ} \tag{9}$$

Where λ is the ratio of the concentration width b_c to the velocity width b_v, ΔU and B are the excess velocity and half width, respectively. U_a is the ambient current velocity.

SITE CHARACTERISTICS

San Francisco outfall is a part of the South West Ocean Outfall Project (SWOOP). The outfall system consists of three submerged diffusers. Sanitary waste water (dry weather) was discharged through the main diffuser, extending approximately 6400m offshore in a depth of 22.9m. Two additional diffusers were designed for discharging storm water runoff (wet weather). The wet weather system was located approximately 3700m offshore with the discharged depth of 13.7m.

Maximum flow rate for both dry and wet weather outfall were 8.1 and 17.85 m^3s^{-1}, respectively. The behavior of discharged plume was analyzed with a laboratory experiment. All tests were performed in a long flume with 10.67m long, 0.61m width and 0.61m depth. Laboratory experiment was conducted to combination of discharged nozzles arrangement and current velocity (0,0.129 and 0.257 ms^{-1}). In all tests, flow discharged horizontally and the density difference at discharge depth for wet and dry weather were 0.0246 and 0.025 gcm^{-3}, respectively (Isaacson et al., 1978 , Isaacson et al., 1983).

RESULTS AND DISCUSSION

15 test cases of wet weather and 7 test cases of dry weather in unstratified conditions were chosen to simulate with VISJET and CORMIX2, since CORMIX2 has a limitation of predicting initial dilution in stratified condition (the depth of stratified layer in CORMIX2 is limited between $0.4H$ to $0.9H$). Predicted dilution by CORMIX2 and VISJET models and laboratory data in both wet and dry conditions are listed in Table 1 and 2, respectively.

Table 1: Results of laboratory experiment and predicted dilution obtained from CORMIX2 and VISJET,(Wet weather).

Test Number	Port Diameter (m)	Diffuser Length (m)	Discharged Depth (m)	Current Velocity (ms^{-1})	Measured Laboratory Dilution	CORMIX 2 Predicted Dilution	VISJET Predicted Dilution
1	0.178	901	12.8	0	47	43.9	40.61
2	0.178	901	12.8	0.129*	67	93.4	38.88
3	0.254	901	12.8	0	38	43	28
4	0.254	901	12.8	0.129	58	93.2	40.78
5	0.254	901	12.8	0	38	13.6	28
6	0.254	901	12.8	0.129	50	85.4	39.36
7	0.254	901	12.8	0.257	89	143.2	109.07
8	0.254	597	12.8	0	35	11.4	27.72
9	0.254	597	12.8	0.129	40	60.1	35.92
10	0.254	597	12.8	0.257	64	97	81.43
11	0.206	901	12.8	0	48	43.7	34.64
12	0.257	901	12.8	0	38	24	28.38
13	0.178	901	12.8	0	51	53.3	40.61
14	0.224	901	12.8	0	42	28	32.82
15	0.267	901	12.8	0	38	24	28

* counter-current discharge

Table 2: Results of laboratory experiment and predicted dilution obtained from CORMIX2 and VISJET.(Dry weather).

Test Number	Port Diameter (m)	Diffuser Length (m)	Discharged Depth (m)	Current Velocity (ms^{-1})	Measured Laboratory Dilution	CORMIX2 Predicted Dilution	VISJET Predicted Dilution
16	0.094	862	24.38	0	169	120.3	205.15
17	0.135	431	24.38	0	99	76.3	134.59
18	0.135	2189	24.38	0	238	216.9	213.4
19	0.135	862	24.38	0	138	117	134.59
20	0.082	1558	22.86	0	192	182.2	259.66
21	0.082	880	22.86	0	139	130.9	201.88
22	0.094	862	24.38	0	139	133	187.5

Comparison of laboratory study and two mixing zone model indicates that both model are relatively in good agreement with experimental data. The results of CORMIX 2 in wet and dry condition had on average +6.5% and -13% errors, respectively. Standard deviations for CORMIX2 predictions were also 47% and 9.7% for wet and dry weather, respectively. The predicted results of CORMIX2 model for dry weather is well supported regarding ±50% error stipulated by the model. In the stagnant condition, CORMIX2 is not able to predict plume dilution properly when the nozzles are arranged against each other (Case numbers 5 and 8). However in this condition VISJET model performed well. Dilution predicted by VISJET had on average -13% and +22.8% errors for wet and dry weather, respectively. Standard deviations of VISJET model prediction are 20% and 21% for wet and dry conditions, respectively. Initial dilution obtained from laboratory experiment, CORMIX2 and VISJET are shown in Figure 2.

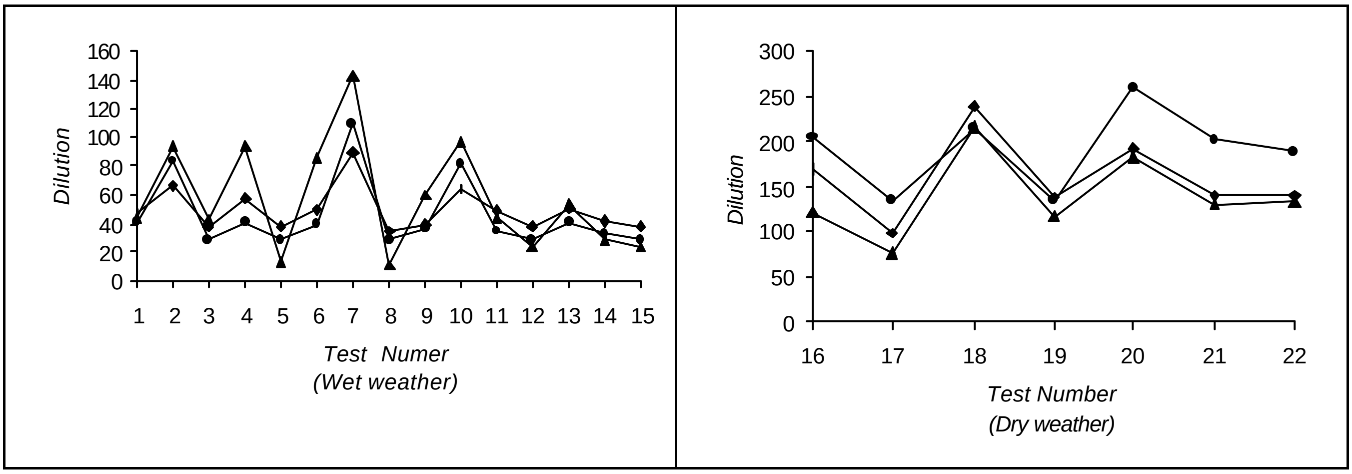

Figure 2: *Comparison of observed and predicted minimum dilution by VISJET and CORMIX2 for San Francisco Outfalls; Diamonds ( ) are the experimental data, Circles ( ) are the VISJET results and triangles ( ) are the CORMIX2 results.*

Comparison of CORMIX2 and VISJET outputs against laboratory observations is illustrated in Figure 3.

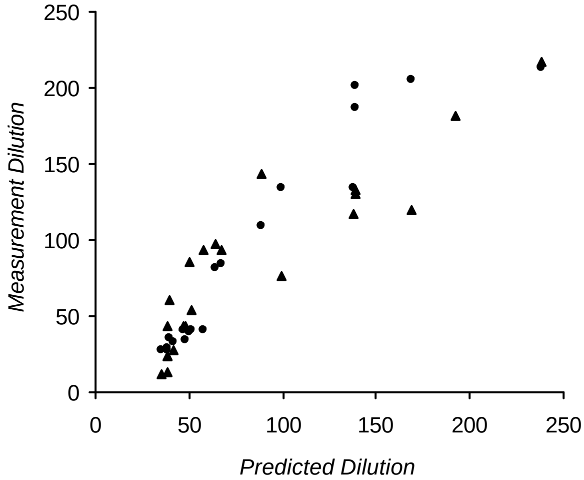

Figure 3: *Comparison of observed and predicted minimum dilutions against VISJET and CORMIX2 models. Circles ( ) are the VISJET results and triangles ( ) are the CORMIX2 results.*

SUMMARY AND CONCLUSIONS

In this study, diffusers with clusters of ports are simulated with two mixing zone models, a length scale model (CORMIX2) and an integral type model (VISJET). Comparison of laboratory data and numerical simulations indicates that both models have good correlation with laboratory data. The results obtained from CORMIX2 imply that, in jet/plume regime, CORMIX2 perform better than VISJET whereas, in near jet regime, CORMIX2 results sometimes over/under shoots the measured dilutions.

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