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Status and Efficiency of Wastewater Sea Outfalls in Korea

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Abstract : *This study provided the status and efficiency of the domestic wastewater sea outfalls based on the previous numerical and experimental studies for the analysis of the buoyant discharges from Rosette diffuser in shallow water. The VISJET model and the hybrid model proposed by Kim (2002) can be proper models for the domestic sea outfalls. The experimental results show that the merging height for MBR and MIR depends on the riser diameter and spacing between risers, and the bending characteristics of the buoyant discharges in still ambient water have significant impacts on the dilution. The current wastewater outfall systems in Korea are not effective for the environmental aspect due to the low discharge water depth. The strategies to reduce the contamination near the domestic wastewater outfalls were found to require the sufficient discharge water depth, proper diffuser location considering the tidal currents, enough riser diameter, and sufficient spacing between risers.*

Key words : *Sea outfalls, Wastewater, Rosette diffuser, Merging, Bending trajectory, Dilution*

1. Introduction

Wastewater produced due to industrialization and population increase is discharged into oceans through treatments of sewage. The most effective ways of reducing the harmful impact of these treated sewage on the ocean environment are to use a well-designed diffuser structure and to discharge the wastewater into deep water. The wastewater multiport diffusers with risers have been used throughout the world. The multiport diffuser can be classified into Rosette, uni-directional and alternating diffusers as shown in Fig. 1. Among these types of diffusers, the Rosette-type diffusers are constructed in relatively shallow water ranging between 6 m and 27 m of depth in Korea. Fig. 2 shows the domestic sea outfalls.

The experimental, theoretical, and numerical studies for the behavior of buoyant wastewater discharged from the Rosette diffuser have been widely performed by many researchers (e.g. Roberts and Snyder, 1993; Lee *et al.*, 2000; Yeo, 2000; Kim *et al.*, 2001; Kim, 2002; Kang *et al.*, 2002; Seo *et al.*, 2004; Kwon, 2005; Kwon and Seo, 2005).

In 1993, Roberts and Snyder performed the experiments to describe the behavior of multi-jets discharged from the Rosette diffuser with eight ports in each riser for the Boston outfall. Lee at al. (2000) provided the VISJET model, which was developed for the analysis of jet discharges into stagnant and moving ambient, even in the case of a Rosette diffuser. Yeo (2000) performed the hydraulic experiments for the buoyant discharges from the domestic Rosette diffuser in flowing ambient as well as still ambient. Kim (2002) suggested the hybrid model to predict the mixing processes for the case of a Rosette diffuser in both near and far fields. Kang *et al.* (2002) conducted the field measurements for the tidal currents, CTD (Conductivity, Temperature, and Depth), and water quality and performed the analysis for the behavior of buoyant discharges. Seo *et al.* (2004) proposed the empirical equations for the merging height and surface minimum dilution in the Rosette diffuser. Kwon and Seo (2005) conducted the hydraulic experiments for a Rosette diffuser using PIV (Particle Image Velocimetry) and LIF (Laser Induced Fluorescence) and observed the bending characteristics of buoyant discharges in still ambient water.

This study provides the methodologies and results of the domestic studies rather than the foreign studies. The objective of this study is to present the status and efficiency of the wastewater sea outfalls in Korea based on the previous results. This study will also show future studies for the improvements of the researches related to the behavior of the buoyant wastewater discharges from a Rosette diffuser.

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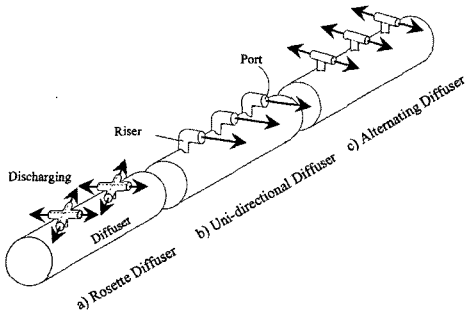


Fig. 1 Classification of submerged multiport diffusers

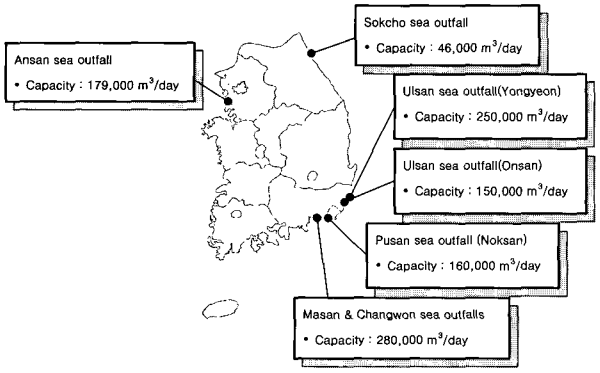


Fig. 2 Domestic wastewater sea outfalls

2. Numerical Methodology

The analysis of the Rosette diffuser in relatively deep water has been conducted by using the concept of line plume (Brooks, 1972; Roberts, 1993a and 1993b) or equivalent array of ports in a straight line in the CORMIX 2 model (Jirka and Akar, 1991). RSB model is based on the experimental studies of multiport diffusers while CORMIX 2 model is based on the flow classification scheme and length scale. RSB and CORMIX 2 models have been widely used for the basically Rosette diffuser, uni-directional diffuser, and alternating diffuser. However, these analyses are suitable only for a multiport diffuser, submerged at great depth to provide sufficient distance for the merging of individual jets prior to the water surface. When the multiport diffuser is located at a shallow depth, jets may not merge or may merge at a relatively short distance from the interaction of individual jets up to the water surface. Roberts and Snyder (1993) showed that the RSB model well simulated the observed plume behavior for the Boston outfall due to the great depth of 32 m.

VISJET model is a robust Lagrangian jet model developed for analysis and prediction of average characteristics of jet discharges into stagnant and moving ambient (Lee *et al.*, 2000). However, this model does not take into account of the interaction between neighboring buoyant jets.

A three-dimensional σ-layered particle-tracking far field model was developed and combined with a jet integral model to make a hybrid model in order to predict the mixing characteristics of the wastewater effluent discharged from sea outfalls (Kim, 2002). The hybrid model consists of the near field mixing represented by a jet integral model and the far field simulated by a particle tracking model. The initial mixing and advection-diffusion processes are coupled properly into the hybrid model using the particle introduction concept. Fig. 3 shows the conceptual diagram of the hybrid model.

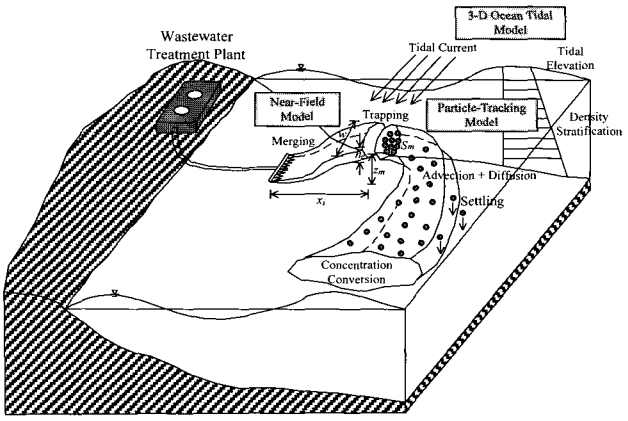


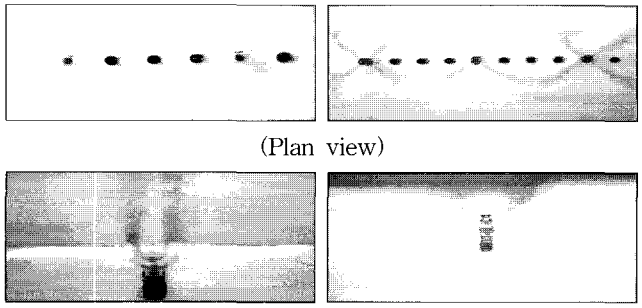
Fig. 3 Conceptual diagram of the hybrid model

3. Experimental Methodology

The buoyant jets were experimented in a flume. The model of the diffuser was manufactured to reflect the representative characteristics of the geometry of the Rosette-type diffusers and the conditions of the sewage water discharged from the sea outfall in Korea. The effluent was supplied from a specially manufactured hot water bath. The discharge from the constant head tank to the diffuser pipe was measured using an electro-magnetic flow meter. The temperature was measured using CC-Type thermocouple sensors. Thermocouple sensors were connected to a data logger, in which the measured temperatures were stored in digital form (Yeo, 2000). Fig. 4 shows the buoyant discharges from a Rosette diffuser in the hydraulic experiments. Here, h is the effective depth of discharge, d is the port diameter, F_j is the initial densimetric Froude number describing the ratio of the inertial forces to the buoyancy forces.

The hydraulic model experiments were also performed using the PIV and LIF system to investigate the bending characteristics of the horizontal buoyant jets discharged from a Rosette-type riser with six and eight ports as well

as mainly four ports in still ambient water over a certain range of the experimental conditions including the momentum and buoyancy (Kwon and Seo, 2005). The model of the diffuser was also based on the representative characteristics of the geometry of the Rosette-type diffusers and the conditions of the wastewater discharged from the domestic sea outfall. Fig. 5 shows the instantaneous image focusing a buoyant jet among the buoyant jets discharged from four ports.

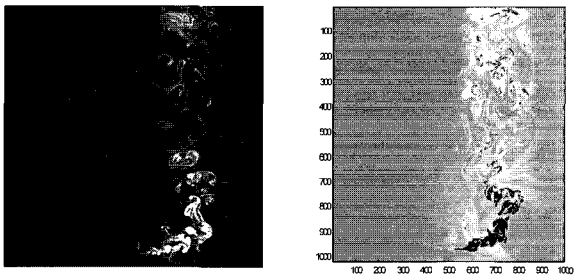


(Plan view)

(Side view)

(a) h/d = 45.45, F_j = 0.6 (b) h/d = 25.45, F_j = 4.03

Fig. 4 Buoyant discharges from a Rosette diffuser



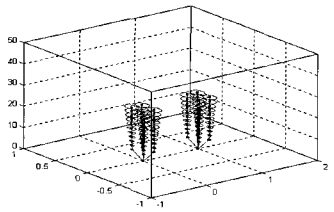
(a) Instantaneous image captured by LIF (b) Instantaneous concentration profile

Fig. 5 Buoyant discharge from a Rosette diffuser (F_j = 8.06)

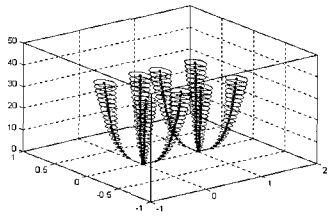
4. Results

The results are described based on the domestic studies for the buoyant discharges from a Rosette diffuser. The numerical results show that two different merging processes can occur according to the densimetric Froude number: MIR (merging in riser) and MBR (merging between risers) as shown in Fig. 6.

A depositional trend of the contaminated sediment was found from the measured data (Kwon and Lee, 1998). The concentrations computed the hybrid model proposed by Kim (2002) were applied to the data measured in the vicinity of the wastewater outfall located in Masan-Jinhae Bay as shown in Fig. 7. This figure shows that the computed concentrations fall in the ranges of the measured values except for site b. This is considered to be because contaminated sediments contained in the inflow from inland streams contribute to high concentrations of the trace metals at site b.



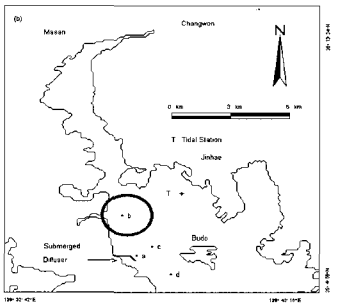
(a) Simulated trajectory for low F_j



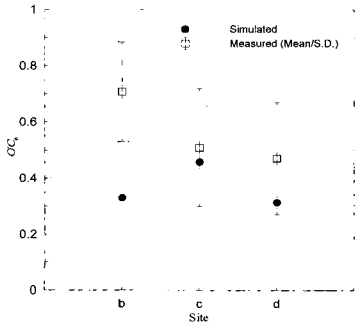
(b) Simulated trajectory for high F_j

Fig. 6 Perspective view of the simulated trajectories of buoyant discharges from a Rosette diffuser

The mixing characteristics of the Rosette-type diffuser consisting of four horizontal ports in each riser were investigated by collecting extensive experimental data at a wide range of discharge and still water conditions in relatively shallow water using a diffuser model and thermocouple (Yeo, 2000).



(a) Measurement sites in Masan-Jinhae Bay



(b) Comparisons of relative sediments concentrations

Fig. 7 Application of the hybrid model to the field measurements

The merging height diagram based on empirical equations for MIR and MBR is presented in Fig. 8. Note, in this figure, that the merging height for MBR increases with increasing value of l/d or decreasing value of D/d, whereas the merging height for MIR increases with increasing value of D/d. Here, z_m is the merging height, D is the riser diameter, and l is the spacing between risers. The proposed empirical equations for MIR and MBR generally agree well with the measured data. This diagram can be used to find the value of z_m when F_j is given for the certain diffuser with known values of l/d and D/d.

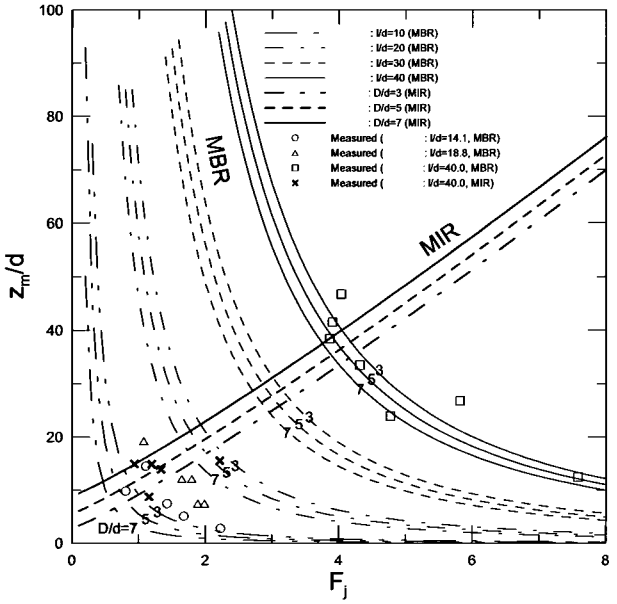
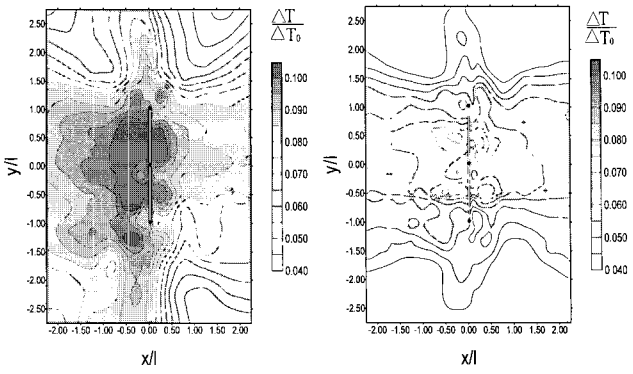


Fig. 8 Diagram of merging height for MIR and MBR

The surface minimum dilution was observed to significantly increase with the increase of discharge depth as shown Fig. 9. Fig. 10 provides the relation between the measured dilution data and discharge depth and the comparison of measured data to the single port equation proposed by Cederwall(1968) and line plume equation suggested by Brooks (1972). The measured surface minimum dilution gradually increases before h/d of 28 and decreases between h/d of 28 and 32 probably due to the increased merging effect. As shown in this figure, line plume analysis and CORMIX 2 model tend to underestimate the measured values especially in shallow water without merging or with slightly partial merging, whereas the results by the line plume analysis and CORMIX 2 model are in generally good agreements with the measured data obtained for condition of relatively deep water with increased merging.



(a) h/d = 11.1, F_j = 4.13 (b) h/d = 15.75, F_j = 4.05

Fig. 9 Isotherm of excessive temperature at water surface

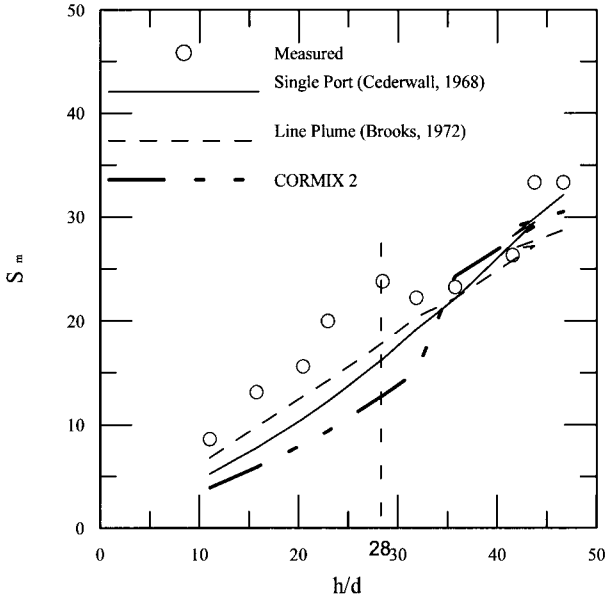
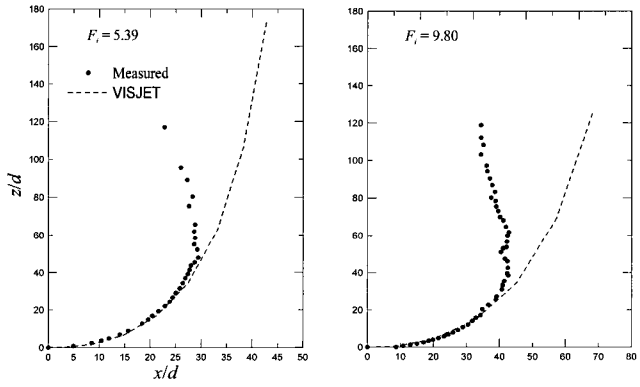


Fig. 10 Surface minimum dilution for Rosette diffuser (F_j = 3.80 - 4.13)



(a) (b)

Fig. 11 Centerline trajectories of buoyant jet discharged from Rosette diffuser (D/d = 6.0)

From the hydraulic model experiments using the LIF and PIV, the bending centerline trajectories were clearly

observed within a certain range of F_j on a Rosette diffuser in still ambient water and were found to have significant effects on the dilution and merging position of the horizontal buoyant jets measured (Kwon and Seo, 2005). The VISJET did not simulate the bending trajectories well after the bending point whereas the trajectories predicted by the VISJET generally were in good agreement with the measured data before bending (Fig. 11). Here, x is the horizontal Cartesian coordinate to jet direction, and z is the vertical distance to water surface.

Fig. 12 shows the centerline dilutions of the buoyant jets discharged from one, four, six and eight ports. Here, S_c is the centerline dilution. The initial centerline dilutions seem to be almost coincident regardless of the number of ports because the buoyant discharges up to a certain vertical distance behaves as a single horizontal buoyant jet without any interaction of adjacent buoyant jets. However, the increasing rate of the centerline dilution tends to decrease as the number of ports increases. The centerline dilution for the multi-ports on the Rosette-type riser can gradually approach to that for single port because the bending trajectory affecting significantly the merging height gradually disappears as the densimetric Froude number increases. In other words, the merging position resulting from the bending height can have significant impacts on the centerline dilution for the multi-ports on the Rosette diffuser.

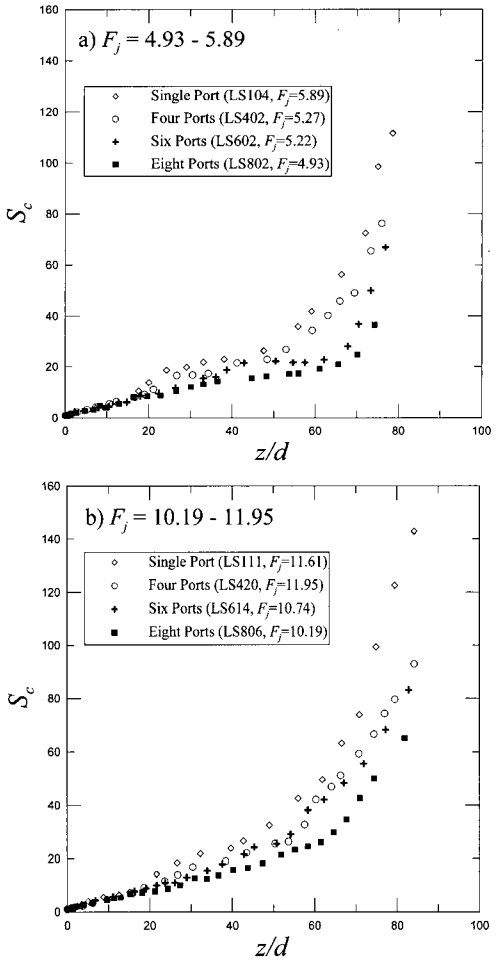


Fig. 12 Comparison of centerline dilutions according to number of ports in similar Densimetric Froude numbers

5. Conclusions and Recommendations

This study summarized the studies for the behavior of the buoyant jets discharged from Rosette diffuser. The RSB, CORMIX 2, and VISJET models have been used for the analysis of the behavior of buoyant discharges from Rosette diffusers. The RSB and CORMIX 2 models are found to be improper models for the analysis of the buoyant discharges from the domestic diffusers in shallow water because these models are based on the line plume concepts. The VISJET model did not simulate the bending trajectories observed by Kwon and Seo (2005) after the bending points in still ambient water. However, the VISJET model can be valid for the analysis of the buoyant jets in flowing ambient. The hybrid model consisting of the near field mixing represented by a jet integral model and the far field simulated by a particle tracking model was used for the prediction of the buoyant discharges from Rosette diffuser. The concentrations computed by this hybrid model generally agree with the data measured in far field.

The experimental results show that the merging height for MBR increases with increasing l/d or decreasing D/d, whereas the merging height for MIR increases with increasing D/d. The surface minimum dilution was observed to significantly increase with the increase of discharge depth. The low merging height resulting from the bending effects can have significant impacts on the dilution for the multi-ports on the Rosette diffuser. Currently, the wastewater outfall systems in Korea are not effective for the environmental aspect due to the low discharge water depth and the location of the diffuser in closed bay. Therefore, the strategies to solve the low dilution which are common in the vicinity of the domestic wastewater outfalls may require the sufficient discharge water depth, proper diffuser location considering the tidal currents, enough riser diameter, and sufficient spacing between risers.

Based on the results, the numerical model considering the axi-symmetric approach up to the merging position and plane plume concept after the merging point may improve the analysis for the behavior of buoyant discharges from

Rosette diffuser in especially shallow water. In addition, the jet integral model taking into consideration the bending effects needs to be numerically investigated and developed. The hybrid model combining this jet integral model will improve the prediction of the water quality in far field as well as in near field because the prediction of the initial behavior can significantly affect the behavior of the plume in far field.

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