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Influence of ambient flow on the behavior of dense effluent discharged into the water environment

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ABSTRACT: Due to the limitation of natural freshwater resources and population growth in recent decades, human has turned to the development of water desalination plants to fill the gap between supply and demand. The most important environmental problem of desalination plants is the production of brine (containing a high concentration of salt) that is discharged directly into the sea. Various factors affect the dilution rate of discharged effluent, one of the most important of which is the ambient flow. In this study, using CorJet integral model, the effect of ambient flow velocity on the characteristics of jets and plumes and their dilution rates are investigated. The direction and magnitude of the ambient flow affect the mixing of the discharged effluent. This effect is the greatest when the ambient flow velocity is higher than the discharged effluent velocity. In this case, the effluent is completely diverted from its original path and advected in the direction of the ambient flow. In the presence of ambient flow, the greater the discharge angle relative to the horizon, the greater the effluent trajectory length and dilution rate. Furthermore, the discharge angle of 90° results in the highest dilution rate of effluents when the ambient flow is present. When the angle between the effluent discharge and the ambient flow ($0 < \phi < 180$) increases, the jet trajectory length, the horizontal distance from the discharge point to where the effluent impacts the ground, and the effluent dilution rate decrease..

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1- Introduction

The construction of desalination plants has increased over the past decades and their brine discharge has negatively impacted the marine environment. Desalination of seas and oceans water, in addition to its benefits of producing potable water, causes damage to the aquatic environment. The most important adverse impact on the ecosystem and aquatic creatures occurs during dewatering the seawater and discharging effluents (brine) with high salt concentration and temperature into the sea [1]. To reduce the environmental impact, the discharged effluent should be mixed with the fluid of receiving environment and diluted in the shortest time and space [2]. The parameters of both discharged jets and receiving environment affect the mixing and dilution of effluents. Among various parameters, the velocity and direction of the environmental flow are some of the most important factors (in both surface and submerged discharges). Numerous studies have been conducted to characterize the release of discharged effluents from desalination plants. Most of these studies have been performed in quiescent environments, while studies in dynamic environments are very limited. In this research, the effect of velocity and direction of ambient flow on the dilution and other characteristics of dense effluents (discharged with angles, θ, of 30, 60 and 90 degrees relative to the horizon, in the sea environment) were investigated. The CORJET integral model was used for modeling. The effect of the environmental flow velocity and direction on the parameters of the discharged effluent, including the horizontal location of the centerline peak (Xm), the horizontal location of the impact point (Xi), and minimum centerline dilution at the impact point (Si) (depicted in Figure 1) were presented. Furthermore, the optimal discharge angle of effluents in terms of the highest dilution rate is determined.

2- Methodology

CorJet [3] is an accurate, three-dimensional integral model for analyzing the concentration and trajectory of discharged effluents in the marine environment. CorJet model predicts the dilution of effluents with positive, neutral and negative densities using the Eulerian integral method. Both single- and multi-port dischargers can be modeled by CorJet. This model also considers the magnitude and direction of ambient flow. CorJet models the effluent discharge in the near-field and does not predict the dilution in the far-field. CorJet has the capability to simulate multilayer environments with different densities [4]. According to previous studies [4-5], the CorJet model has reasonable accuracy in simulating dense wastewater discharged in dynamic environments. In this present study, to validate the model, the results obtained by

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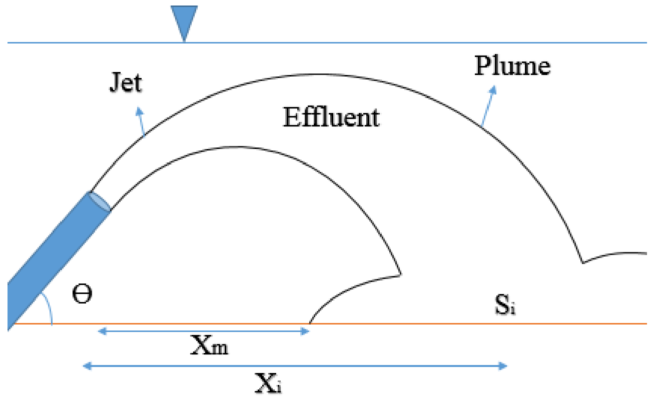

Fig. 1. Schematic of submerged discharge of dense effluent. Xm is the horizontal location of the centerline peak, Xi is the horizontal location of the impact point, Si is the minimum centerline dilution at the impact point, and θ is the discharge angle relative to the horizon.

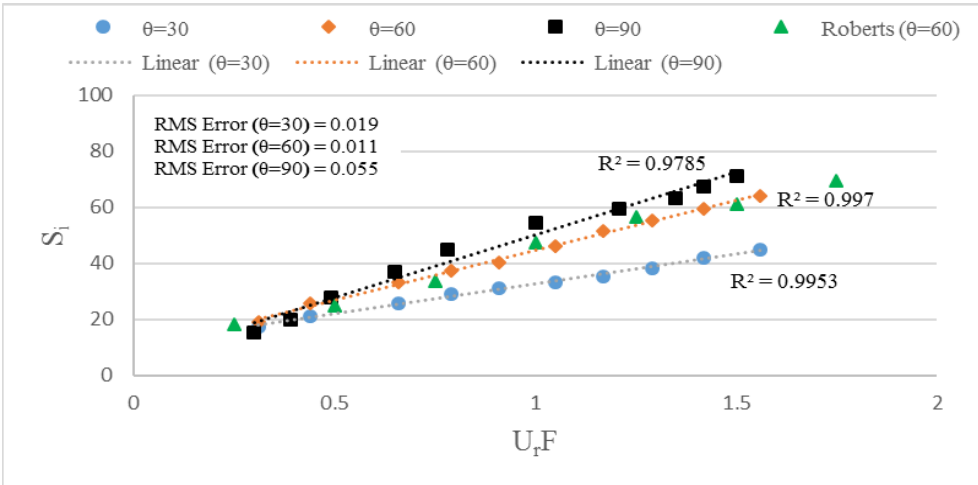

Fig. 2. Comparison of dilution of dense effluent with different discharge angles in the case of ϕ = 0 (co-flow).

CorJet were first compared with those of laboratory studies [6-7]. The results computed by the CorJet model were in good agreement with those of laboratory studies conducted in dynamic environments.

3- Results and Discussion

As the ambient flow velocity increases, the value of Xm increases linearly for all discharge angles. In effluent discharge in low ambient velocity ($UrF < 0.3$), the value of Xi has the highest and lowest values for 30 and 90° angle dischargers, respectively. For the cases with high ambient velocities ($UrF > 1.5$), the value of Xi has the lowest and highest values for 30 and 90° angle dischargers, respectively. Furthermore, the value of Xi increases as the ambient flow velocity and discharge angle increase. The value of parameter Xi for vertical discharge of dense effluent is independent of the angle between the direction of ambient flow and effluent discharge (ϕ) and the value of Xi is constant for all values of ϕ. Figure 2 shows the dilution rate of the discharged effluent at the impact point as a function of ambient flow velocity. In this figure, $Ur = U_a/U_j$, where Ua is the ambient flow velocity, Uj is the jet exit velocity, and F is Froude number. As the ambient flow velocity increases, the dilution rate in all dischargers increases almost linearly. At low ambient flow velocities ($UrF < 0.5$), the effluent discharged at a 60° angle has the highest dilution. On the other hand, at high ambient flow velocities ($UrF > 0.5$), the effluent discharged at a 90° angle has the highest dilution. At high ambient flow velocities ($UrF > 0.5$), as the effluent discharge angle increases, the dilution increases. Dilution of the discharged effluent in the co-flow is reduced relative to the discharges in the counter-flow.

4- Conclusions

In this study, using the CorJet integral model, the effect of ambient flow velocity and direction on the dilution (Si) and trajectory (Xm and Xi) of the discharged effluent was investigated. According to the results, the velocity and direction of the ambient flow is an important factor in changing the dynamics and mixing of dense effluents. When the effluent is discharged in the direction of the ambient flow (co-flow), the ambient flow increases the trajectory length of the effluent in the jet and plume mode. Therefore, the dilution rate of the effluent increases. The greater the angle between the direction of discharge of the effluent and flow of the environment ($0 < \phi < 180$), the less the jet trajectory length, and as a result, the dilution rate of the effluent decreases. If the effluent is discharged in the opposite direction of the ambient flow (counter-flow), the jet trajectory length and the dilution rate will have the lowest value compared to those of the other angles ($0 < \phi < 180$). As the ambient flow velocity increases, the dilution rate of the discharged effluent increases almost linearly. At low ambient speeds (UrF < 0.5), the effluent discharged from the discharger at a 60° angle has a higher trajectory length (and, therefore, has more contact with the ambient fluid), resulting in a higher mixing rate. At high ambient speeds (UrF > 0.5), as the discharge angle increases, the discharged effluent travels a greater distance horizontally along with the ambient flow, and as a result, its dilution rate increases. For the range of parameters studied, the best method to discharge dense effluents (to achieve maximum dilution) in the high-velocity environment (UrF > 0.5) is to use 90° (vertical) angle dischargers.

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