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Effects of Discharges Source Section on Flow Characteristics of Negatively Buoyant Effluent

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1-Introduction

Nowadays, the reduction in the cost of water production in desalination plants around the world is growing rapidly in number and size and hence the amount of brine flow increases. The desalination processes include removing the suspended matter and the dissolved minerals (mainly salt) from seawater or brackish water to produce fresh and drinkable water. It leads to production of a highly concentrated waste water which essentially discharges into coastal waters through marine outfalls. The discharging is mainly done using outfalls which are designed as submerged and surface structures. The majority of the studies in the past have focused on the surface discharge of positive buoyant flow that have different flow characteristics compared to those of dense surface discharges. Most of these studies focused on the determination of key flow characteristics in stagnant waters. Regardless of the importance of the effect of the geometry of the source, no study has been reported in the literature. The analysis of buoyant surface jets can be separated into the near-field and far-field regions. The near-field region is where the mixing is strongly dependent on the discharge conditions. It is the only region of the mixing region that can be controlled by the design engineer. Jones et al. (1996) reported that the discharge flow characteristics within the near-field in stagnant ambient can be determined by eight variables such as the Initial Volume ($Q_0 = U_0 . A_0$), Momentum ($M_0 = Q_0 . U_0$), Buoyancy Fluxes $B_0 = Q_0 . g_0$, where $g_0 = \left({}^{\Delta\rho_0}/_{\rho_a} \right) . g$ is initial reduced gravity term, g is acceleration, (U0) is discharge velocity, (A0) is discharge channel section and the width and depth is (h_0, b_0), the ambient velocity s (u_a), the distance along trajectory is (X), and the ambient water depth is (H). Using dimensional analysis, flow geometrical and mixing properties can be linked to the discharge feature and initial flow fluxes. Thus, the discharge length scale (L_Q) and jet to plume length scale (L_M) were used to describe the properties of buoyant jet flows. L_Q describes the region where discharge channel geometry extremely influences the flow properties. L_M represents the location where the transfer from momentum-dominated region (jet-like behavior) to the buoyancy-dominated region (plume-like behavior) happens into unstratified stagnant ambient. The ratio of these two length scales is expressed as the densimetric Froude number ($Fr_d = \frac{L_M}{L_Q} = \frac{u_0}{\sqrt{g.A_0^{1/2}}}$). Really, in this study the effect of channel geometry, the rectangular and trapezoidal section, on surface dense flow the characteristics were experimentally investigated. Dense flow behavior was reported for Densimetric Froude number less than twenty. So, the self-similarity property of flow is not established in these experiments.

2. Experimental method

The experiments were conducted in the Hydro-environmental research laboratory at Iran University of Science and Technology (IUST) by discharging a continuous flow of brine into a glass-walled tank with a length of 6.00 m, the width of 1.80 m, and the depth of 1.5, filled with fresh water. The surface discharges were two steel channel with rectangular and trapezoidal sections, 10 cm width for both where depths varied from 0.66 to 2.4 cm for rectangular channel and varied from 0.8-2.3 cm, for trapezoidal section with side slope equal to Z=1.5. Discharge densimetric Froude numbers ($Fr_d = \frac{u_0}{\sqrt{g_0.A_0^{1/2}}}$) in the range of 1.7 -4.93 were used with the channel Reynolds numbers ($\mathrm{Re} = \frac{u_0.h_0}{\nu}$ where ν is kinematic viscosity) in the range $of\ Re > 500$. Brine density has been changed within the range of 1.01-1.053 $\frac{g}{cm^3}$ for the salinities of 22.2-73.4 ppt and temperatures in the range of 20 to $24C^0$.

In this paper a new simple non-intrusive optical technique was used to define flow properties. The experiments were conducted in a dark room in front of a uniform light source of fluorescent lamps by the frequency of 50 HZ. 35 frames were captured for each second by a camcorder, extracted then for pre and post processing. The image stream Ver. 7.0 software was used to obtain the average image to determine the light intensity of each pixel. The IrfanView software was also utilized to convert the average colorful picture of the experiment into inverted gray scale images in which the light intensity of each pixel ranges from 0 to 255 with minimum for pure white and maximum of pure black. For image processing, the light intensity for each pixel of the averaged-gray scaled image was

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analyzed using the codes developed by the MATLAB software.

3. RESULTS

The results of a comprehensive experimental study on the impact of the outfall source shape on the flow characteristics in surface discharge of negatively buoyant effluent in stagnant water were done on two sections of rectangular and trapezoidal shapes.

The data collected from each experiment were processed to obtain the trajectory centerline maximum. In each of the sections with increase in the densimetric Froude number (Fr_d), horizontal advancing (X) along the jet trajectory increases. One major difference in the trajectories of the trapezoidal section, if compared to rectangular section (with similar kinematic and buoyancy characteristics), is that the horizontal progression and trajectory are longer for the trapezoidal section (Figure 1). This means that a trapezoid section travels longer horizontal distances ($\frac{X}{L_M}$) than a rectangular section, to reach a certain elevation ($\frac{Z}{L_M}$)..

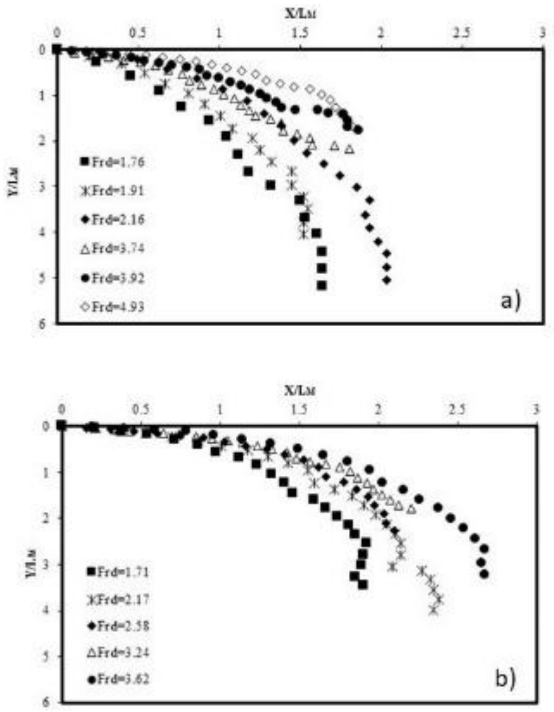

Figure. 1: Experimental result of surface discharge of dense buoyant jet, (a) rectangular section, (b) trapezoidal section

In this study, the jet width is determined as the distance from the jet centerline where the intensity value is 1/e of the maximum intensity value, thus $I(b_v) = \frac{1}{e} I_{\max}$.

In jet like regions for both sections, the trend of changes in flow width was overlapping in all profiles and varies linearly with a steep slope. In plume like regions, the slope against the jet like region has nonlinear trend and its slope is less than the jet region (Figure. 2).

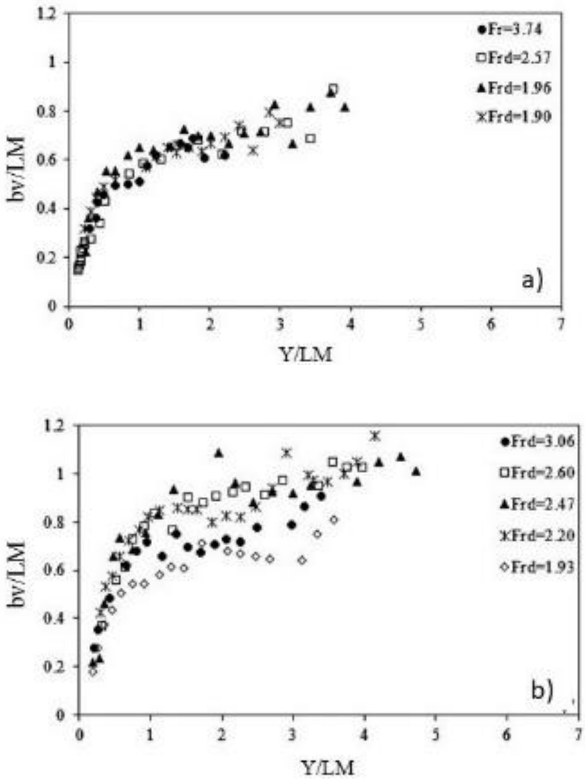

Figure 2: Flow width variation of surface discharge in negatively buoyant waste water downward the bed (Z-axis) (a) rectangular section, (b) trapezoidal section]

In this study, in order to study the profiles of flow concentration in different directions, the intensity of black light was extracted in different transverse sections perpendicular to the central line of the current for both rectangular and trapezoidal sections.

4. Conclusion

In this research, the source geometry effect on surface discharge of negatively buyout effluents from discharging channel were studied and the effective dimensionless parameters were investigated; and flow pattern, concentration profiles, change width and flow trajectory were scrutinized. The results indicated that trapezoidal sections were performed better than rectangular sections for Fr<20. The result of flow behavior in these sections indicates that despite similar behavioral pattern, geometric and mixing characteristics of trapezoid are better than those of a rectangular section.