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An experimental study to improve the design of brine discharge from desalination plants

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Abstract: An experiment was performed in water resources engineering department laboratory at Lund University of Sweden to investigate the behavior of inclined negatively buoyant jets. Such jets arise when brine is discharged from desalination plants and improved knowledge of their behavior is required for designing discharge systems that cause a minimum of environmental impact on the receiving waters. In the present study, a turbulent jet with a specific salinity was discharged through a circular nozzle at an angle to the horizontal into a tank with fresh water and the spatial evolution of the jet was recorded. In total, 72 experimental cases were carried out where four different initial jet parameters were changed, namely the nozzle diameter, the initial jet inclination, the jet density (or salinity), and the flow rate (or exit velocity). The measurements of the jet evolution in the tank included five geometric quantities describing the jet trajectory that are useful in the design of brine discharge systems. From the data analysis some geometric quantities describing the jet trajectory showed strong correlations. Also, the results confirmed that the new relationships between the parameters can develop the current knowledge for the new plan to design desalination plants outfall. Thus, if the vertical and horizontal distance to the maximum centerline level (or, alternatively, the maximum jet edge level) can be predicted, other geometric quantities can be calculated from the regression relationships that were developed.

Keywords: Desalination, Lab-Scale Experiment, Turbulent Jet, Negative Buoyancy, Brine Modeling

1. Introduction

1.1. Background, Objectives, and Procedure

The high-salinity desalination brine is produced that needs to be discharged into a receiving water with a minimum of environmental impact. The brine is typically discharged as a turbulent jet with an initial density that is significantly higher than the density of the receiving water (ambient), where the difference in density between the jet and the ambient may be up to 4-5%. Thus, a rapid mixing of the discharged brine is desirable to ensure minimum impact, which requires detailed knowledge of the jet development. Since the density of the jet is larger than the density of the receiving water, the jet is negatively buoyant and it will impinge on the bottom some distance from the discharge point depending on the initial momentum, buoyancy, and angle of the discharge, as well as the bathymetric conditions. After the jet encounters the bottom it will spread out as a gravity current with a low mixing rate, making it important to achieve the largest possible dilution rate when the jet moves through the water column.

However, relatively few studies have been conducted on negatively buoyant jets, especially with regard to experimental work. The present investigation focuses on collecting data through a laboratory experiment on the evolution of a negatively buoyant jet with the purpose of: (1) increasing our understanding of the behavior of such jets, (2) developing empirical relationships for predictive purposes, and (3) calibrating and validating numerical models. Only the two first aspects are discussed in the present paper, and for numerical modeling of the collected data [1].

The experiment was performed to investigate the behavior of inclined negatively buoyant jets. A turbulent jet with a specific salinity was discharged through a nozzle at an angle to the horizontal into a tank with fresh water and the evolution of the jet was recorded. The measurements of the jet evolution in the tank included five geometric quantities describing the jet trajectory that are useful in the design of brine discharge systems. Thus, the collected data encompassed the maximum rise level of the jet and its horizontal distance, the maximum level of the jet centerline and its horizontal distance, and the distance to the edge point (where the jet returns to the discharge level).

1.2. Previous Relevant Studies

Dense jets, being a particular type of negatively buoyant flows, have been studied by several authors, for example, [2-11]. In an early study, Zeitoun *et al*. [12] investigated an inclined jet discharge, focusing on an initial jet angle of 60 deg because of the relatively high dilution rates achieved for this angle.

Cipollina *et al*. [13] extended the work performed in previous studies on negatively buoyant jets discharged into calm ambient by investigating flows at different discharge angles, including 30, 45, and 60 deg, and for three densities 1055, 1095 and 1179 kg/m^3. Kikkert *et al*. [14] developed an analytical solution to predict the behavior of inclined negatively buoyant jets and reasonable agreement was obtained with measurements for initial discharge angles ranging from 0 to 75 deg and initial densimetric Froude numbers from 14 to 99. An experiment was carried out by discharging dense jets consisting of a saltwater solution, with density differences 2% – 3.5% (higher than the ambient) into a large tank with dimensions 3.0m x 1.5m x 1.0m (length (*L*), width (*W*), and depth (*D*)) filled with tap water. From these experiments, Papakonstantis *et al.* [15] concluded that the particular experimental conditions may affect the determination of the maximum height of rise initially.

For instance, the fluid which remains in the pipeline prior to the start before each run may be warmer or colder than the effluent from the denser tank. Most of the experimental data reported concern the maximum level of the jet flow edge, which is usually taken from visual (photographic) observations. This involves considerable subjective judgment, with possible related errors depending on the type and amount of dye used, the illumination level and the sensitivity of the recording method [16].

Christodoulou and Papakonstantis [17] studied negatively buoyant jets with discharge angles between 30^o and 85^o. Mixing and re-entrainment are both important in negatively buoyant jets. These phenomena have been experimentally studied and discussed by [18]. They found that re-entrainment tends to appear if the angle exceeds 75^o with respect to the horizontal, and the onset occurs for lower angles as the Froude number increases. The re-entrainment makes the jet trajectory bend on itself, causing a reduction of both the maximum height and the distance to the location where entrainment of external fluid reaches the jet axis [18]. Papakonstantis *et al.* [19] studied six different discharge angles for negatively buoyant jets from 45 to 90 degrees to the horizontal. They used a large-size tank and also measured the horizontal distance from the source to the upper (outer) jet boundary at the source elevation.

2. Jet Properties and Dimensional Considerations

An inclined negatively buoyant jet discharged upwards at an angle towards the horizontal is shown in Fig. 1, representing the typical case of a brine jet being discharged to a receiving water. The jet describes a trajectory that reaches a maximum level, after which the jet changes its upward movement and plunges towards the bottom. Since the jet is negatively buoyant, the initial vertical momentum flux driving the flow upwards is continuously reduced by the buoyancy forces until this flux becomes zero at the maximum level and the jet turns downwards.

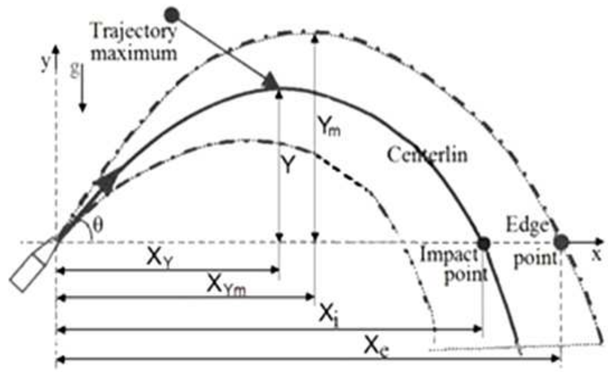

Fig 1. *Definition sketch for inclined jet parameters (after [13])*

Knowledge of the shape of the jet trajectory is important in the design of brine discharge. Major variables that previously have been employed to describe the jet trajectory (with respect to the location of the jet origin based on a *x-y* coordinate system) are: the maximum level of the jet centerline Y and its horizontal distance X_y, the maximum level of jet flow edge Y_m, and its horizontal distance X_{ym}, and the maximum horizontal distance to the jet flow edge point X_e (that is, where the jet returns to the discharge level); see Fig. 1. In general, the location of the jet edge may be defined as the maximum jet height boundary at any particular location.

The jet is discharged at a flow rate Q_o through a round nozzle with a diameter d_o, yielding an initial velocity of u_o, and at an angle θ to the horizontal plane. The initial density of the jet is ρ_o and the density of the receiving water (ambient) ρ_a, where ($\rho_o > \rho_a$), giving an initial excess density in the jet of $\Delta\rho = (\rho_o - \rho_a) \ll \rho_a$ (the Boussinesq approximation). Similar flow problems were previously analyzed through dimensional analysis by [2,8,13,20,21].

Most previous studies assumed that the Boussinesq approximation is valid and that the flow is fully turbulent. Thus, the initial jet properties can be characterized by the volume flux Q_o, the kinematic momentum flux M_o, and the buoyancy flux B_o, as defined in Fischer *et al*. [21], together with the initial jet angle θ (the subscript o denotes conditions at the nozzle).

2.1. Dimensional Analysis Considerations

The leading variables in the dimensional analysis may be written for a round jet with uniform velocity distribution at the exit:

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2.1. Dimensional Analysis Considerations

The leading variables in the dimensional analysis may be written for a round jet with uniform velocity distribution at the exit:

$$Q_o = \frac{\pi d_o^2}{4} u_o, M_o = \frac{\pi d_o^2}{4} u_0^2 \quad B_o = g \frac{\rho_o - \rho_a}{\rho_a} Q_o = g' Q_o \quad (1)$$

where g = acceleration due to gravity, and $g' = g(\rho_o - \rho_a)/\rho_a$ = the modified acceleration due to gravity. A dimensional analysis involving Q_o, M_o, and B_o yields two length scales that may be used to normalize the above-mentioned geometric quantities and to develop empirically based predictive relationships [21]:

$$l_M = \frac{M_o^{3/4}}{B_o^{1/2}} \quad \text{and} \quad l_Q = \frac{Q_o}{M_o^{1/2}} \quad (2)$$

By using the bulk quantities Q_o, M_o, and B_o, the nozzle shape and the initial velocity distribution is implicitly taken into account. For a uniform velocity distribution, $l_Q = \sqrt{A_o}$ and if the nozzle is circular $l_Q = d_0\sqrt{\frac{\pi}{4}}$. The length scale l_Q quantifies the distance over which the initial volume flux constitutes a significant portion of the local jet volume flux, or in other words, where the entrained ambient water and Q_o is of the same order [22]. Thus, for distances from the nozzle much larger than l_Q, Q_o will not be of significance. The length scale l_M represents the distance over which the transition from jet to plume behavior takes place in a stagnant uniform ambient [23].

At distances from the nozzle much greater than l_M the effect of M_o becomes negligible and the buoyant jet has essentially become a plume. For a negatively buoyant jet discharged upwards, the initial momentum flux will always be an important parameter during the phase when the jet is moving upwards, because M_o and the buoyancy are not acting in the same direction [10]. The importance of these length scales has been discussed by several authors, including Wright [22] and Fischer *et al.* [21].

Thus, since any dependent variable describing the jet flow will be a function of Q_o, M_o, and B_o only, the maximum level of the jet centerline (Y), for example, can be expressed in terms of the two length scales [8-10]:

$$\frac{Y}{l_M} = f\left(\frac{l_M}{l_Q}\right) \quad (3)$$

For $l_m >> l_Q$, the effects of Q_o becomes negligible, and Eq. (3) simplifies to:

$$\frac{Y}{l_M} = K \quad (4)$$

where K is a constant. For a circular jet, the length scale l_M may be written,

$$l_M = \frac{M_0^{3/4}}{B_0^{1/2}} = (\frac{\pi}{4})^{1/4} d_0 F_0 \quad (5)$$

where F_0 is a densimetric Froude number defined by ($u_0 / \sqrt{g' d_0}$). Thus, Eq. (4) can be rewritten:

$$\frac{Y}{d_0} = k * F \quad (6)$$

where $k = K(\pi/4)^{1/4}$. Similar equations may be developed for the other geometric jet quantities Y_m, X_y, X_{ym}, and X_e, but with different values on the coefficient k.

3. Laboratory Experiments

3.1. Experimental Setup

The experiment on inclined negatively buoyant jets was carried out in the laboratory of Water Resources Engineering at Lund University. The apparatus and major equipment used in the experiment included water tanks, a flow meter, a digital frequency recorder, a digital conductivity meter, pump, pipes, valves, nozzles and nozzle support, salt, and dye (see Fig. 2). Several different tanks were used in the experiment: (1) a small tank to mix tap water with salt and a coloring dye to obtain saline water for generating an easily visualized negatively buoyant jet, (2) two elevated small tanks used to create the hydraulic head for generating the jet, and (3) a large tank made with glass walls filled with tap water (fresh water) where the jet was introduced through a nozzle. The small tanks were made of plastics and their volumes were 45, 70, and 90 liters, whereas the maximum volume of the large tank was 540 liters with the bottom area dimensions of 150 x 60 cm^2 and a height of 60 cm.

Two of the smaller tanks were placed at a higher elevation compared to the large tank to create the necessary hydraulic head for driving the jet. These two tanks were connected by a pipe and together they had a sufficiently large capacity (*i.e.*, surface area) to keep the water level approximately constant in the two tanks during the experiment to ensure a constant flow.

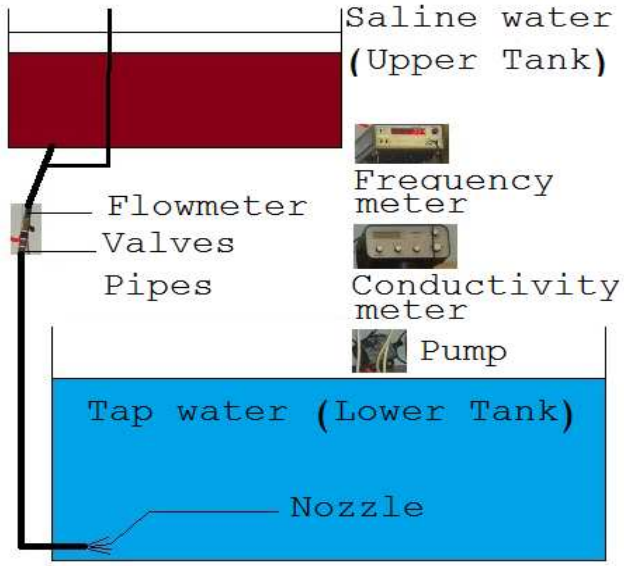

Fig 2. *Experimental setup and major used components*

The difference in elevation between the water levels of the upper tanks and the lower tank was about 100 cm. The colored saltwater from the upper tanks was discharged through a plastic, transparent pipe directly connected to the jet nozzle, which was fixed at the bottom of the large water tank. Between the elevated tanks and the nozzle there was a valve to control the flow to the nozzle. A flow meter was installed in the pipe between the valve and the outlet from the upper tanks in order to record the initial jet flow. This meter was connected to a digital frequency recorder, from which the readings where converted into flow rates based on a previously derived calibration relationship. The employed nozzle diameters were 1.5, 2.3, 3.3, and 4.8 mm (inner diameter), and the initial jet inclination angles 30, 45, and 60 deg to the horizontal (see Fig. 1). The dimensions of the lower water tank was 150cm x 60cm x 60cm (L x W x H), where the depth of water above the nozzle was about 45cm. The nozzle was placed about 5cm above the tank bottom.

3.2. Experimental Procedure and Data Collected

Before starting an experimental case, it was crucial to empty the pipe leading from the upper tanks from air. This was done by attaching a special pipe to the flow meter and discharging tap water through this pipe, bringing out the air from the system. After each experimental case a submersible water pump was used to completely empty the large tank, so that each case started with water that was not contaminated by salt.

With the capacity of the pump, it took about 12 minutes to empty the tank. Also, the whole system was regularly washed to avoid accumulation of salt, which would disturb the experiment. Fine pure sodium chloride was used to create the saline water in the jet by mixing it with tap water. The necessary water quantity was measured in a bucket and the mass of salt was measured using a balance to obtain the correct salt concentration. A conductivity meter was employed to measure the conductivity for the three different concentrations investigated. The density measurements for these concentrations yielded 1011, 1024 and 1035 kg/m^3 for 2, 4 and 6%, (20, 40, and 60 g/l), respectively.

The temperature of the tap water used in this experiment was in the range 20 to 22 C° for all cases, implying a density of about 995.7 kg/m^3. Each of the densities was the average of five different measurements based on the weight method. Differences in the density were observed between the salt water used in this study and natural seawater. The chemical composition of seawater is different from the sodium chloride solutions used here, although the density varies only slightly in seawater compared with the pure sodium chloride solutions.

Potassium permanganate ($KMnO_4$) was used to color the saline water and make the jet visible during the experiment. The dye gives the transparent water a distinct purple color by adding about 100 mg/l. The use of a colored jet facilitated the observation of the jet trajectory and the mixing behavior in the larger water tank. The results of jar tests for different ($KMnO_4$) concentrations showed that at a concentration of 0.3 mg/l the water is still colored, whereas at concentration of 0.2 mg/l no color was visible to the eye.

4. Results and Discussion

The densimetric Froude number (F_0) quantifies the relative importance of the momentum and buoyancy force.

A small F_0-value indicates that the buoyancy force controls the jet behavior, shortening the trajectory length. On the other hand, a large F_0-value signifies initial dominance of momentum and a longer trajectory, although eventually the buoyancy forces will still prevail and deflect the jet towards the bottom. Analysis of the video films taken during the experiment showed that small F_0-values were associated with less fluctuation in the jet behavior and a more stable trajectory compared to jets with large F_0-values. It is expected that smaller density differences between the jet and the ambient (corresponding to larger F_0 values) will produce a jet more prone to instability behavior resulting in a less stable trajectory; compare with [24,25]. However, this observation was not as clear for the experimental cases with the smaller salinity.

4.1. Jet Trajectory Analysis

As previously mentioned, in total 72 experimental cases were carried out with different jet quantities. As an example, Fig. 3(a) illustrates the relationship between Y_m and Y for all the cases. A very strong correlation between the two quantities is found, lending some confidence to the accuracy of the measurements. The least-square fitted line through the origin yields a slope of about 1.25, implying that Y_m on the average is about 25% larger than Y.

Figure 3(b) shows the relationship between X_y and X_{ym}, which also indicates a strong correlation with limited scatter around the least-square fitted straight line through origin.

The slope of this line was about 1.20, which is somewhat lower than what the relationship between Y and Y_m yielded. Furthermore, the horizontal distance to edge point of the jet (X_e) showed rather good correlation with X_{ym} (or X_y), as displayed in Fig. 3(c), although the scatter was larger than for the previously discussed relationships (*e.g.*, Fig. 3(a) and 3(b)). The slope of the least-square fitted line was approximately 1.65. Figure 3(d) shows Y as a function of X_y with respect to the initial jet angle (θ).

Since Y is closely dependent on θ, the analysis for the different angles should be performed individually. Thus, in the figure, separate lines are least-square fitted to the data for the three investigated initial jet angles (30, 45 and 60 deg).

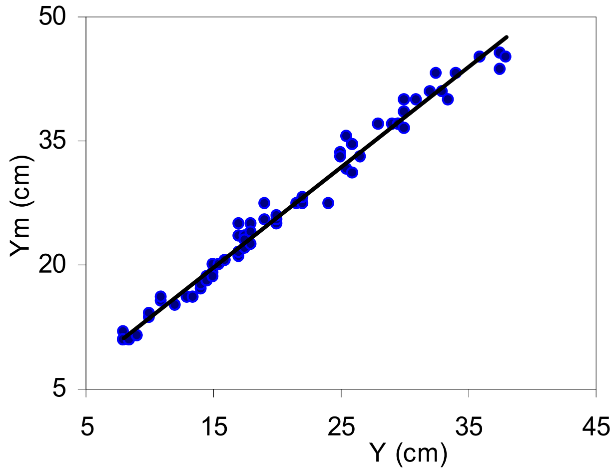

Fig. 3(a). *Relationship between maximum level of jet centerline (Y) and maximum edge level (Y_m) for all experimental cases*

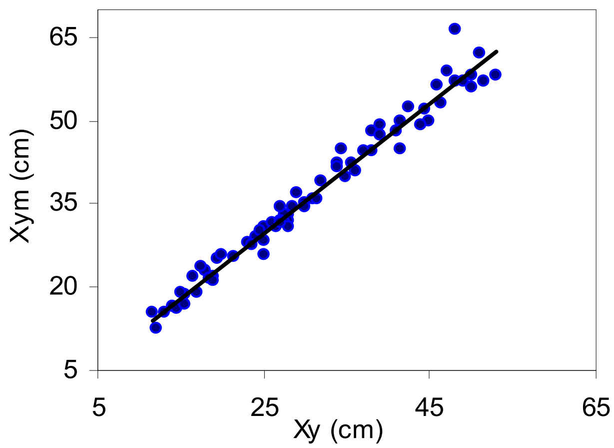

Fig. 3(b). *Relationship between horizontal distance to maximum jet centerline level (X_y) and maximum edge level (X_{ym}) for all cases*

The slopes of the fitted straight lines were 2.3, 1.5, and 1.0 for 30, 45, and 60 deg, respectively. If a simple ballistics model was employed to describe the jet trajectory (*i.e.*, constant g'), the ratio between X_y and Y would be given by 2/(tan θ), which yields the following slopes for the lines: 3.5, 2.0, and 1.2. Thus, the simple ballistics model would overestimate X_y/Y, but progressively less for larger angles. The spread of the data in Figure 3(d) around the regression line for each angle indicates that the trajectories are not simply scale copies of each other, but other factors influence the shape of the trajectories. However, as the angle increases the effect of these factors become smaller.

Equation 4 indicates a linear relationship between the normalized quantities to describe the jet trajectory and the F_0. However, this is built on the assumption that $l_m >> l_Q$, otherwise Eq. 3 should be employed. Developing Eq. 3 by introducing the definition of the length scales yields,

$$\frac{Y}{d_0} = k * F * \Psi(F) \tag{7}$$

where Ψ = function and Y is used as an example of a geometric jet quantity. If F_0 is small $\Psi(F_o) \rightarrow 1$, whereas for large F_0 values $Y \rightarrow \infty$. The data indicates a relationship for large F_0 where $Y / d_0 \propto F_0^n$, with $n < 1$. Based on the theoretical constraints and the empirical observations, the following equation was proposed to describe Y/d_o as a function of F_0 over the entire range of experimental data.

$$\frac{Y}{d_0} = \frac{k * F}{(1+\alpha F)^m} \tag{8}$$

where α and m are empirical coefficients obtained from fitting against data. Equation 8 can be approximated with a straight line in accordance with Eq. 6 for small values on α F_0.

Figure 4 shows an example of least-square fitting Eq. 8 against the data for the maximum jet centerline level (Y) and an initial jet angle of 30 deg, where the optimum values on K, α, and m were determined (1.35, 0.008, and 0.8, respectively). Overall the trend of the data points is well described, but the significant scatter for $Fr_d > 100$ is still present, which degrades the agreement. The other initial angles for Y and the other jet quantities could be fitted about equally well.

5. Discussion

Some geometric quantities describing the jet trajectory showed strong correlations, for example, Y_m versus Y, X_{ym} versus X_y, and X_e versus X_{ym}. Thus, if the vertical and horizontal distance to the maximum centerline level (or, alternatively, the maximum jet edge level) can be predicted, other geometric quantities can be calculated from the following regression relationships:

$$\left.\begin{aligned} Y_m &= 1.25Y \\ X_{ym} &= 1.20X_y \\ X_e &= 1.65X_{ym} \end{aligned}\right\} \tag{9}$$

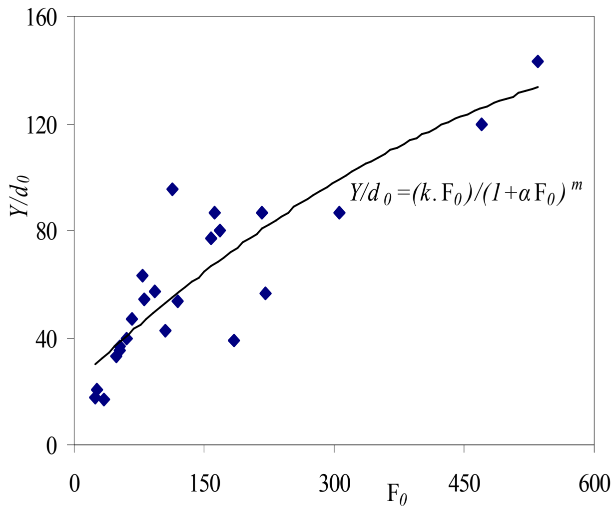

Fig. 4. *Normalized maximum jet centerline level as a function of F for an initial jet angle of 30 degrees*

The relationship between the maximum levels and their horizontal distances displayed more scatter (see Fig. 3(d)) and included a dependence on the initial jet angle. However, a general equation of linear type could be fitted through the data points with reasonable accuracy,

$$X_y = k_\theta Y \tag{10}$$

where k_θ is an empirical coefficient that takes on the value 2.3, 1.5, and 1.0 for the initial jet angle 30, 45, and 60 deg, respectively. A similar equation could be developed for X_{ym} and Y_m. Inclined negatively buoyant jet is an efficient method to improve the dilution rate of brine discharged from a desalination plant into the receiver [26]. The empirical relationships developed in this study have a potential for use in practical design where the trajectory of brine jets needs to be estimated. The finding in this study will useful on the local and farther scale especially for the design of mixing wastewater with brine. This mixing reduces the salinity gradients in the coastal areas. It will be possible to minimize the impact and reduce the salt concentration in the future by adding wastewater to the brine discharge [27].

6. Conclusions

A laboratory experiment was conducted to investigate the behavior of negatively buoyant jets discharged at an angle to the horizontal into a quiescent body of water. The jet was made denser than the surrounding water by adding salt (sodium chloride) at specific concentrations, which increased the density. Several of the geometric jet quantities showed strong correlation, for example, Y_m versus Y, X_{ym} versus X_y, and X_e versus X_{ym}, and regression relationships could be developed where one quantity can be predicted from another. If maximum levels were correlated with the corresponding horizontal distances, the angle must be taken into account when developing predictive relationships.

Equations were proposed to relate levels or horizontal distances to each other, that is, Y_m to Y, X_{ym} to X_y, and X_e to X_{ym}. In order to relate a level to the corresponding horizontal distance, F_0 may be employed in non-dimensional equations where the initial jet angle is included as well. For example, knowledge of the initial jet parameters yields the F_0 value, from which the maximum level of the jet centerline can be calculated.

The results of these measurements confirmed that the new relationships between the parameters can develop the current knowledge for the new plan to design desalination plants outfall. Some geometric quantities describing the jet trajectory showed strong correlations. Thus, if the vertical and horizontal distance to the maximum centerline level (or, alternatively, the maximum jet edge level) can be predicted, other geometric quantities can be calculated from the regression relationships that were developed.

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References

[1] Sánchez, D. (2009). Near-field evolution and mixing of a negatively buoyant jet consisting of brine from a desalination plant. Master Thesis at the dept. Water Resources Engineering, Lund University.

[2] Turner, J.S. (1966). Jets and plumes with negative or reversing buoyancy. J. Fluid Mech. 26 779–792.

[3] Abraham, G. (1967). Jets with negative buoyancy in homogeneous fluid. J. Hyd. Res. 5 (4) 235–248.

[4] Tong, S.S., Stolzenbach, K.D. (1979). Submerged discharge of a dense effluent. Rep. No. 243, Ralph M. Parsons Laboratory, Massachusetts Institute of Technology, Cambridge, Mass.

[5] James, W.P., Vergara, I., Kim, K. (1983). Dilution of a dense vertical jet. J. Environ. Eng., 109 (6) 1273–1283.

[6] McLellan, T.N., Randall, R. (1986). Measurement of brine jet height and dilution. J. Waterw., Port, Coast, Ocean Eng. 112(2), 200–216.

[7] Baines, W.D., Turner, J.S., Campbell, I.H. (1990). Turbulent fountains in an open chamber. J. Fluid Mech. 212, 557–592.

[8] Roberts, P.J.W., Toms, G. (1987). Inclined dense jets in flowing current. J. Hydraulic Eng. 113(3), 323–341.

[9] Roberts, P.J.W., Toms, G. (1988). Ocean outfall system for dense and buoyant effluents, J. Environ. Eng., 114(5) 1175–1191.

[10] Roberts, P.J.W., Ferrier, A., Daviero, G. (1997). Mixing in inclined dense jets. J. Hydraulic Eng. 123(8), 693–699.

[11] Zhang, H., Baddour, R.E. (1998). Maximum penetration of vertical round dense jets at small and large Froude numbers. J. Hyd. Eng., ASCE 124 (5) 550–553, Technical Note No. 12147.

[12] Zeitoun, M.A., Reid, R.O., McHilhenny, W.F., Mitchell, T.M. (1972). Model studies of outfall systems for desalination plants. Office of Saline Water Research and Develop. Progress Rep. 804. U.S. Dept. of the Interior, Washington DC.

[13] Cipollina, A., Brucato, A., Grisafi, F., Nicosia, S. (2005). Bench scale investigation of inclined dense jets. J. Hydraulic Eng. 131(11), 1017–1022.

[14] Kikkert, G.A., Davidson, M.J., Nokes, R.I. (2007). Inclined negatively buoyant discharges. J. Hydraulic Eng. 133(5), 545–554.

[15] Papakonstantis, I., Kampourelli, M., Christodoulou, G. (2007). Height of rise of inclined and vertical negatively buoyant jets, Proc. 32nd IAHR Congress, Venice, Italy.

[16] Jirka, G.H. (2008), Improved discharge configuration forbrine effluents from desalination plants. J. Hydr. Eng, 134 (1), 116-120.

[17] Christodoulou, G.C., Papakonstantis, I.G. (2010), Simplified estimates of trajectory of inclined negatively buoyant jets, in "Environmental Hydraulics", Taylor & Francis, London, 165-170.

[18] Ferrari, S., Querzoli, G. (2010), Mixing and re-entrainment in a negatively buoyant jet, J. Hydr. Res, 48(5), 632-640.

[19] Papakonstantis, I.G., Christodoulou, G.C., Papanicolaou, P.N. (2011). Inclined negatively buoyant jets 1 – Geometrical characteristics, J. Hydr. Res. 49 (1) 3-12.

[20] Pincince, A.B., List, E.J. (1973). Disposal of brine into an estuary. J. Water Pollut. Control Fed., 45 2335–2344.

[21] Fischer, H.B., List, E.J., Koh, R.C.Y., Imberger, J., Brooks, N.H. (1979). Mixing in Inland and Coastal Waters. Academic Press.

[22] Wright, S.J. (1984). Buoyant jets in density-stratified crossflow. J. of Hydraulic Engineering. ASCE. 110, (5) 643–656.

[23] Doneker, R.L., Jirka, G.H. 2007. A Hydrodynamic Mixing Zone Model and Decision Support System for Pollutant Discharges into Surface Waters. Cormix User Manual 6.0E.

[24] Bleninger, T., Jirka, G.H. (2007a). Modelling and environmentally sound management of brine discharges from desalination plants. Accepted for EDS Congress, April 22-25, Halkidiki, Greece.

[25] Bleninger, T., Jirka, G.H. (2007b). Towards Improved Design Configurations for Desalination Brine Discharges into Coastal Waters. IDA World Congress-Maspalomas Gran Canaria –Spain October 21-26, REF: IDAWC/MP07-139.

[26] Bashitialshaaer, R., Larsson, M., Persson, K.M. (2012) An Experimental Investigation on Inclined Negatively Buoyant Jets. *Water* 2012, *4*, 750-768.

[27] Bashitialshaaer, R., Flyborg, L., Persson, K.M. (2011) Environmental assessment of brine discharge and wastewater in the Arabian Gulf, Desalination and Water Treatment (25) 276–285.