II - 95 VORTEX CONVECTION PRODUCED BY A V-SHAPED DIHEDRAL OBSTRUCTION

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INTRODUCTION

In its' natural and unpolluted state deep-sea water is rich in nutrients, such as phosphorous and nitrate salts, in a suitable ratio to sustain marine life. In certain situations however the deep water can stagnate and become eutrophic. It is thus apparent that a passive, efficient means of raising deep water to the surface would be valuable tool for preserving and improving aquatic environments.

Strong convection can be produced by placing a V-shaped plate in a horizontal flow. Vortices shed from the plate coalesce with neighboring ones to form a horse-shoe shaped vortex. The self-induced upward motion produced due to the shape and the flow converging and surmounting the plate raises the vortex head, resulting in the vertical convection. The dependence of the motion of the three-dimensional vortex filaments on the dihedral angle of the V-shaped dihedral plate, the density and Reynolds number of the mean flow have been numerically simulated.

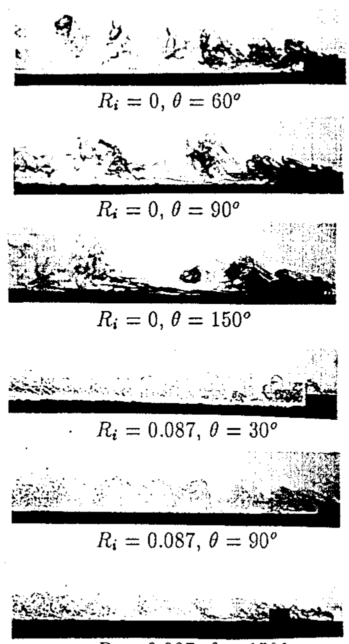
EXPERIMENT

A plume of $8m$ long, $0.42m$ wide was used in experiments. 40 cm deep of salts water with linear density variation was created in plume to serve as stratified environment. A V-shape dihedral plate of $2cm$ high, with each branch of $10cm$ long was placed downward on the bottom of a float, so that a bend points against the moving direction of float. Dihedral angle θ was varied from 30^o to 180^o with increments of 30^o for each measurement. The float can be steadily move along the plume by motor placing on the other end of plume with the help of tiny connecting string. The main velocity in experiments are 2.3, 6.7 and 15.3 cm/s ($R_e = 340$, 1022 and 2335 respectively). The density on the surface was 1.0 g/cm^3 and on the bottom higher 0%, 2%, 4%, 6% and 10% varied for each run. The Richardson number R_i (given by $d\rho/dh/\rho_r.gd^2/U^2$) was introduced. Flow patterns were visualized by injecting dye (water blue) loading on float from three injection pipes mounted at two ends and the center of the plate. As float moves along the plume, the vortices shedding behind the plate can be observed.

Figure 1 shows typical flow patterns. As our interest concentrated in moving of vortices, further analyses are make for opposite direction. A triangular separation zone was formed behind the plate, containing strong recirculation as a result of the vorticity shed from the flow passing over the plate, which will subsequently be called the surmounting flow. The flow passing around the edges of the plate produced a strong vortex with axis aligned perpendicular to the floor, originating from the bottom at the lee-side of the plate end. The two vortices originating at either end of the plate then join with the vortex produced by the surmounting flow to form a single V shaped vortex.

Vortices were generated frequently in the separation zone, resulting in some of them coalescing and forming stronger vortices, before shedding downstream.

After shedding, the vortex head, that is the central region of the V-shaped vortex, was pushed upward by both the surmounting flow and the horizontally converging flow in the wake. Further, vortices affected by the bottom boundary are deformed into a horse-shoe shape. With the repeated generation and shedding of vortices an array of oblique vortices were produced. In homogeneous fluid, the head of each downstream vortex being positioned higher then its' upstream neighbor, forms within a distance of 10 times the plate height. In stratified environment, the vortices also effected by a number of other factors. The circulation of the vortices changes as they move downstream. Furthermore, the difference of density in the core and surrounding fluid pushes vortices down. However with high Reynolds number, the vortices can be convected higher 4-5 times of the plate high.



$R_i = 0$, $\theta = 60^o$

$R_i = 0$, $\theta = 90^o$

$R_i = 0$, $\theta = 150^o$

$R_i = 0.087$, $\theta = 30^o$

$R_i = 0.087$, $\theta = 90^o$

$R_i = 0.087$, $\theta = 150^o$

Fig.1. Flow pattern

The frequency f of the vortex shedding was obtained by a number of vortices passing across a given location during determined interval of time. The Strouhal number, $S_t = fd/U$, where d is the plate height, is shown with respect to the distance from the plate. S_t clearly decreases with increasing θ. The initial vortex circulation is supposed to be the same as the one in homogeneous fluid.

NUMERICAL SIMULATION

A discrete vortex method was used to simulate the behaviour of the vortices in the downstream wake. The velocity of each vortex is assumed equal to the summation of the induced velocities associated with other potential, which includes local velocity due to the main flow and gravity effect due to the density excess with respect to the environment. In the present condition of study, the effect of the free surface and plate on the vortex movement is sufficiently small to be ignored. The governing equations are; the induced velocity of point element $\mathbf{x}$ caused by another vortex

$$\mathbf{u}_1(\mathbf{x}) \simeq -\frac{\Gamma(\mathbf{r},t)}{4\pi}\int_V \frac{(\mathbf{x}-\mathbf{r})\times\frac{\partial\mathbf{r}(s)}{\partial s}ds}{|\,\mathbf{x}-\mathbf{r}\,|^3} \quad (1)$$

where Γ is vortex circulation; the self-induced velocity of point-element $\mathbf{x}$

$$\mathbf{u}_2 \simeq C\Gamma(\mathbf{x},t)(\frac{\partial\mathbf{x}}{\partial s}\times\frac{\partial^2\mathbf{x}}{\partial s^2}) \quad (2)$$

where C is a coefficient regarded as constant; the velocity due to the main flow

$$\mathbf{u}_m(x) = U(\frac{h}{H_o})^{\frac{1}{7}} \quad (3)$$

where H_o is the thickness of the flow and h vertical coordinate of vortex. Since the vortices are considered as material element, the density of liquid inside the core defers with surrounding environment. Let $\Delta\rho$ be this difference, the gravity effect will be $-g\Delta\rho/\rho_r$, (ρ_r is reference density). As vortices move, the density inside the core diffuses, which is assumed by the solution of diffusion $\Delta\rho = \Delta\rho_o[1-exp(-a^2/4Dt)]$, ($D$ diffuse coefficient). The core radius a is approximated as for Oseen vortex: $a = 2.2418(\nu t)^{1/2}$. The turbulent viscous ν is assumed to be $\nu = \alpha\Gamma$. α is constant coefficient. Γ may be determined by equation

$$\frac{D\Gamma}{Dt} = \iint_S \nabla\times F.d\mathbf{A} - \iint_S(\nabla\frac{1}{\rho}\times\nabla p).d\mathbf{A} \quad (4)$$

where F is the body force, p is pressure and A is vortex surface. To be able to calculate the circulation the following approximation are introduced: the velocities are single, the body force is the gravity effect, the pressure is hydrostatic, the density variation is linear. The solution of (4) associated with the initial circulation allow to determine induced velocities. Calculated results are plotted in figure 2 associated with envelope of vortices (spline) obtained in experiment. Calculation have carried out for large range variation of R_i.

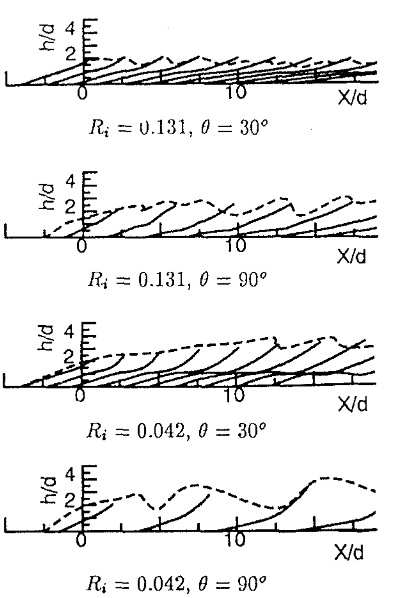


Fig.2. Side view of vortex

CONCLUSION

The hypothesis that for the same R_e and variation of density the rising height of fluid in the wake of a dihedral V-shaped structure will be maximized for the 90^o V has been tested both experimentally and numerically. In homogenous environment this height weakly depends on R_e and can be high as 8 times the high of plate in optimum. In stratified environment it closely depend on R_e and R_i. With large R_e it can be reach 5 times the plate high although fluid are strong dense. With small R_e the rising height active only in weak dense environment.

It is apparent that the 90^o dihedral V-shaped structure is a simple and efficient means of generating an upward rising current. Such a structure may be of practical application in regions with currents that require mixing for environmental reasons.

REFERENCES

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