

Tutorial 1 – Buoyant jet in unstratified stagnant fluid/crossflow (file Tut_1.vj3)

Problem definition

An outfall located in Port Shelter discharges effluent at a rate of $0.03 \text{ m}^3/\text{s}$ with a concentration of 100 units through a diffuser into an otherwise stagnant ambient. The effluent receives primary treatment; the remaining BOD_5 in the effluent is 200 mg/L ; the suspended solids concentration is 90 mg/l ; the total coliform count is 5×10^6 counts/100 mL. The temperature and salinity of the ambient are 15°C and 34.5 ppt respectively; and these for the discharge are 20°C and 1 ppt respectively. You are asked to study the mixing characteristics of the outfall, such as the dilution and trajectory under different design conditions, assuming zero background concentration in the ambient. Tides are present so the tidal current effect should also be taken into account.

The first example is for a single vertical buoyant jet discharge into an otherwise stagnant fluid. For a single jet the riser flow is the same as the jet flow. The main parameters are as follows:

Basic Data:

Outfall Parameters:

Depth (z)	20 m
Flow	$0.03 \text{ m}^3/\text{s}$
Temperature	20°C
Salinity	1 ppt
Concentration	1 relative units
Length	5 m
Diameter	2 m
Distance	2.5 m
Orientation	0°

Ambient Parameters:

Depth	20 m
Temperature	15°C
Salinity	34.5 ppt
Current velocity	0.0 m/s (Current angle 90°)

Jet Parameters:

Diameter	0.1 m
Distance	2.5 m
Vertical angle	90°
Horizontal angle	0°

General Notes:

1. *Creating a scenario*

- (i) Click **File** at the menu.
- (ii) To create a new scenario, select **New**.
- (iii) Give a name to the scenario, type in Tut_1 at the Name blank.
- (iv) Select a folder path to save the scenario.
- (v) Select a Hong Kong location for the simulation. In this tutorial, we will use Port Shelter as an example. Click on Port Shelter.
- (vi) The “type of simulation” does not have any effect on this near-field simulation; you can just select any type. In later tutorials when the far field simulation is performed, the appropriate type needs to be specified

A folder with the name Tut_1 will automatically be created; it is where all the grid information and the VISJET file are contained; check whether it exists in your specified path.

2. *Navigate around the selected topology*

- (i) Left click any point on the screen, the clicked point will automatically become the centre point of the screen.
- (ii) Scrolling down and up will allow you to zoom in and out with the selected point in step (i) as centre
- (iii) left click and hold the mouse button, and freely move the mouse to view the topology at different orientations
- (iv) Select “View” at the menu; you will be able to select what geographical information to be displayed. “Landform”, “Seabed”, and “Outfall” have been pre-selected. Now click on “Water surface” to view the water surface as well.

3. *Select an outfall location*

- (i) Click “**create an outfall without Riser**” to create an outfall.
- (ii) Left click a point on the screen close to the desired outfall location.
- (iii) Click the “Pick” button on the outfall parameters panel.
- (iv) Move the mouse cursor to the desired outfall location, and left click.
- (v) The outfall will then appear at the position of the cursor.
- (vi) The coordinates of the outfall will automatically be calculated and are shown as the X and Y coordinates in the outfall position panel.

4. *Input ambient parameters*

- (i) Click “**New**” once just below the “**Ambient parameters window**”.
- (ii) Input the ambient parameters as given above:


Depth	Salinity	Temperature	Current
0	34.5	15.0	0.0
20	34.5	15.0	0.0

(iii) Keep the “**current angle**” as 90° for this scenario.

(a) Vertical Jet in stagnant fluid

We begin with the simplest case of vertical jet in stagnant fluid.

- (i) Highlight **Outfall #01**
 - (ii) Input the outfall parameters as given above
 - (iii) Click “**New Jet**”
 - (vi) Highlight **Jet #01**
 - (v) Input the jet parameters as given above
- You are now ready to run the simulation

5. Click “**Start Near Field VISJET simulation**”  at the toolbar. You can see the evolution and spread of the jet. In the Lagrangian model, the jet path is made up of a series of plume elements (‘disks’) which vary in position, width, and velocity as they mix with the surrounding fluid. (Note that you may need to zoom in quite a bit to see the jet and outfall as their size is small relative to the whole Port Shelter.)

6. Study how to get the *jet characteristics* of each Lagrangian element: the computed average velocity, maximum concentration, and average dilution at that height.

- (i) Zoom in to the jet and click on any position of the jet you want to get the information
- (ii) Now you can see the ‘disk’ position being display by a red line on the surface of the jet
- (iii) The pop up disk properties windows give various jet information of that particular disk. For example, the centre of Disk #605 is located at (0.00, 0.00,10.74), visual radius = 1.2438 m, thickness = 0.0026 m, vertical angle = 90°, horizontal angle = 0°, average velocity = 0.197 m/s, maximum concentration = 0.0267, average dilution S=63.74 and average concentration = 0.0157.

The dilution is a measure of the degree of mixing achieved by the jet; the inverse of dilution is the relative concentration of any pollutant contained in the discharge.

7. Zoom in closely to the jet. Try to obtain the disk properties close to the jet nozzle. For example, disk #63 is located at (0.00,0.00,0.16), Visual radius = 0.0545 m, thickness = 0.0325 m, vertical angle = 90° , horizontal angle = 0° , average velocity = 2.48 m/s, maximum concentration = 1.000, average dilution $S=1.54$ and average concentration = 0.6476. At a location so close to the source, not much dilution has taken place yet.


8. Try to obtain the disk properties near the water surface. For example, disk #665 is located at (0.00,0.00,14.18), Visual radius = 1.6073 m, thickness = 0.0023 m, vertical angle = 90° , horizontal angle = 0° , average velocity = 0.1780 m/s, maximum concentration = 0.0176, average dilution $S=96.53$ and average concentration = 0.0104. By the time the plume has reached the water surface, a considerable amount of dilution has taken place as water is continuously being entrained into the plume.

9. *Save file*: you can save the current scenario by selecting Save in the main menu File (file format .vj3) for later use.

(b) Horizontal Jet in stagnant fluid – effect of varying jet angle

10. Now we are going to study the effect of varying the jet angle to the jet mixing characteristics.

(i) Keep all discharge parameters unchanged as in part (a) except changing the vertical jet angle from 90° to 0° . We now have a horizontal jet instead of a vertical jet discharge.

(ii) Run the simulation again by clicking “**Start Near Field VISJET simulation**”  at the toolbar.

(iii) Observe the jet evolution and spread from the animation. This time instead of seeing a plume going straight upwards, you would see a jet initially going horizontally, and gradually bends upwards due to the buoyancy force and finally reaches the water surface.

11. Zoom in closely to the jet. Try to obtain the disk properties close to the jet nozzle. For example, disk #65 is located at (0.17,0.00,0.00), Visual radius = 0.0554 m, thickness = 0.0319 m, vertical angle = 0.1469° , horizontal angle = 0° , average velocity = 2.44 m/s, maximum concentration = 1.000, average dilution $S=1.57$ and average concentration = 0.6387. At this location very close to the source, similar to the vertical jet, not much dilution has taken place.


12. Now try to obtain the disk properties near the water surface. For example disk #707 is located at (9.66,0.00,13.24), Visual radius = 1.9457 m, thickness = 0.0021 m, vertical angle = 79.7968° , horizontal angle = 0° , average velocity = 0.1620 m/s, maximum concentration = 0.0132,

average dilution $S=129.07$ and average concentration = 0.0077. Compare the dilution at water surface of the horizontal jet ($S=129.07$) with the vertical jet ($S=96.53$), the horizontal jet has a greater dilution capability!

A horizontal jet entrains more ambient fluid into itself than a vertical jet, resulting in a higher dilution since the jet path of a horizontal jet is longer than that of a vertical jet!

(c) Vertical Jet in a crossflow – Effect of a current

The marine environment is not stagnant for most of time. With even just a slight tidal current the mixing characteristics of a jet can be significantly different. VISJET can illustrate this easily.


13. Returning back to the case of vertical jet by changing the vertical angle of the jet from 0° to 90° . Run the simulation again by clicking **“Start Near-field VISJET simulation”**. 

14. Study the use of **“SUSPEND FILE”**

To obtain the computed result, instead of clicking each disk directly, we may open the SUSPEND file. To open the SUSPEND file, click **“View”** at the main menu, and select **“view SUSPEND file”**. The SUSPEND file shows key input parameters and length scales that govern the mechanics of buoyant jet mixing. For example, Total $Q = 0.03 \text{ m}^3/\text{s}$, jet densimetric Froude number $F_d = 23.96$, buoyancy flux $B_j = 0.00762 \text{ m}^4/\text{s}^2$, jet momentum length scale $l_M = 2.2556$, and so on. The computed jet characteristics (co-ordinates of the jet trajectory, plume visual radius, velocity, concentration, dilution etc.) are tabulated. You will find some information about the surface layer level and the surface dilution. For this case, the surface layer level is 16.40 m above the discharge port, and the average dilution is $S=120.19$. Note that the partial blocking by the free surface is taken into account in this calculation (dilution only up to the base of the surface layer).

15. Study the effect of a current.

(i) Keep all the discharge parameters unchanged except changing the ambient current speed from 0.0 m/s to 0.1 m/s for both depths 0 m and 20 m in the ambient parameters window.

(ii) Re the simulation again by clicking **“Start Near-field VISJET simulation”**. 

(iii) Observe again the jet evolution and spread. Notice any differences. Note that for this time the jet no longer goes straight upwards due to the effect of the current. Instead, the jet is bent over by the current soon after discharge (current direction is indicated by the red arrow near the outfall).

(iv) View the **“SUSPEND FILE”** again, and compare different mixing characteristics with the case with a current.

(v) The dilution for this case is found to be $S=398.12$ at $z=13.42 \text{ m}$ above the port. Compare the dilution with the case without a current ($S=96.53$).

The dilution is increased for nearly 4 times for just a small current!

16. Try out the effect of current of different magnitude. Study their effect on the jet mixing characteristics.

(d) Multiple vertical jets in a crossflow – Merit of multiport diffuser design

17. Consider the vertical buoyant jet in Tutorial 1 again, but this time instead of using one jet, divide the flow of $0.03 \text{ m}^3/\text{s}$ in to 4 jets, each discharge from a different port. So now we have FOUR vertical buoyant jets in a uniform stagnant fluid, but each port discharges $\frac{1}{4}$ of the original flow. The outfall and jet parameters of the multiport diffuser are as follows:

Outfall Parameters:

Depth (z)	20 m
Flow	$0.03 \text{ m}^3/\text{s}$
Temperature	20°C
Salinity	1 ppt
Concentration	1 (relative unit)
Length	60 m
Diameter	2 m
Distance	30 m
Orientation	0°

Jet Parameters:


Flow	$0.0075 \text{ m}^3/\text{s}$
Diameter	0.1 m
Vertical angle	90°
Horizontal angle	0°
Distance:	0 m (jet 1)
	20 m (jet 2)
	40 m (jet 3)
	60 m (jet 4)


18. You can change the orientation of the diffuser with respect to the current by entering the diffuser angle at the **“Angle”** blank.

19. Change the outfall dimensions and parameters as given above (location of the outfall is unchanged).

20. Create the first jet by clicking the **“New Jet”** button. Enter the jet parameters as given above (Note that you don’t need to input the Flow

for the jet, it will automatically be calculated as Outfall Flow/number of jets). Create the remaining jet by clicking the **“New Jet”** button; pay attention especially to the distance of each jet. (Instead of entering the distance of each jet manually, a short cut is to first create an outfall with length 60 m, then click the **“Distribute jets evenly”** button, jets will then be automatically separated at a distance (s) equal to $L/(n-1)$ where L is the diffuser length and n is the number of jets.

21. Re-run the **“Near-field VISJET simulation”**  and see the evolution of the jets. At this jet separation distance, do neighbouring jets interact with each other (do they overlap)?

22. You can see more clearly on the jet interaction by cutting a vertical plane on the jet group. To view the cross-sectional plane of the jet group, choose vertical plane and click **“toggle clip plane”**  at the menu bar. You would then see a clip plane is created on the main screen. The green circle on the clip plane is used to translate the position of the clip plane. Left click and hold the green circle to move back and fro; you would see the cross-sectional view of the jet group. The yellow triangle of the clip plane is used to rotate the angle of the clip plane, try left click and hold the yellow triangle to move left and right; you can see the angle of the clip plane being rotated. In this way the extent of merging of the rosette jet group can clearly be visualized.

23. Study the mixing characteristics of the multiple jet discharge.

(i) Open the **“SUSPEND FILE”**.

(ii) The mixing characteristics of each jet is tabulated. For example in Jet #01, Total $Q = 0.0075 \text{ m}^3/\text{s}$, jet densimetric Froude number $F_d = 5.99$, buoyancy flux $B_j = 0.00191 \text{ m}^4/\text{s}^2$, jet momentum length scale $l_M = 0.5639$, and so on. Note the difference between these and the case with only a single port discharge.

(iii) Study the dilution of the jet group. The average dilution of this case is $S=2304$ at 12.13 m above the port, much higher than that of a single port discharge!

Multiport diffuser give significantly higher dilution than that of a single port discharge!

24. *Multiple jet interaction.*

(i) Now change the outfall length from 60 m to 10 m. Follow the steps in 20. to distribute the jets evenly along the diffuser (jet spacing should be 3.3 m).

(ii) Run the simulation again. Can you see the interaction (overlapping) of the jets? Try to toggle the clip plane and cut a cross-section at different position of the jet group and see the extent of overlapping.

(iii) For closely spaced jets, they would interact and merge with each other, causing a reduction in dilution. This merging effect has been taken into account by VISJET through computation of the overlapped area. The resulting composite dilution is available in the VISJET 2 software.

Calculations of concentration of water quality parameters

It is given in the problem that the BOD₅ in the effluent is 200 mg/l; the suspended solids in the effluent is 90 mg/L; and the coliform count is 5x10⁶ counts/100 mL. With the near field dilution computed by the VISJET model, we now can calculate the concentration of these quantities at the water surface at the end of the initial dilution zone, assuming zero concentration background in the ambient.

Example calculation:

For the case of a vertical jet in stagnant water, average dilution obtained S= 96.53.

Thus the concentration of BOD₅ for this case is 200/96.53 = 2.07 mg/L

Concentration of the suspended solid = 90/96.53 = 0.93 mg/L

Coliform count = 5x10⁶ / 96.53 = 5.2 x 10⁴ counts/100mL

The water quality parameters at the end of the initial dilution zone are summarised as follows:

Quantities	Vertical jet in stagnant water	Horizontal Jet in stagnant water	Vertical jet in a crossflow	Multiple vertical jets in a crossflow
Dilution	96.53	129.07	398.12	2304
BOD ₅ (mg/L)	2.07	1.55	0.50	0.087
Suspended solid (mg/L)	0.93	0.70	0.23	0.04
Coliform (counts/100 mL)	5.2 x 10 ⁴	3.9 x 10 ⁴	1.26 x 10 ⁴	2.2 x 10

25. Close this file and start the next tutorial.