Numerical simulation of deepwater oil blowout: crossflow effect

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1. Introduction

In 2010, one of the largest offshore oil spills of all time happened in the Gulf of Mexico, USA. For the first time, the sub-sea injection of chemical dispersants was used to treat deepwater oil spills. However, with only few studies prior to its application, the overall effectiveness of this method is still under investigation as appropriate measures of the oil droplets were not performed in situ. In order to investigate the impact of the water current crossflow in an oil blowout, we apply Computational Fluid Dynamics simulation to study this phenomena by using dimensionlessnumbers, which allow us to assess the effect of several parameters in the oil jet behavior.

In this research, we investigate three parameters that influence the jet under crossflow: the Weber number ($We_w = \rho_w U^2 D/\sigma$), the Reynolds number ($Re_w = \rho_w UD/\mu$), and the inlet velocity ratio ($r = U_o/U_w$), where ρ is the density, D is the oil inlet diameter, U is the inlet velocity, μ is the water viscosity, and the subscripts w and o indicates water and oil, respectively.

2. Numerical Methods

The numerical simulations of oil blowout in a cross flow were executed using the schematics shown in Fig. 1a. The governing equations solved are the Continuity (Eq. 1) and Navier-Stokes (Eq. 2) equations:

$$\frac{\partial \alpha_k}{\partial t} + \boldsymbol{u_k}.\nabla\alpha_k = 0 \tag{1}$$

$$\frac{\partial(\rho_k\alpha_k\boldsymbol{u_k})}{\partial t} + (\rho_k\alpha_k\boldsymbol{u_k}.\nabla)\boldsymbol{u_k} = -\alpha_k\nabla p + \nabla.(\mu\alpha\nabla\boldsymbol{u_k}) + \rho_k\alpha_k\mathbf{g} + \boldsymbol{F_{D,k}} + \boldsymbol{F_{S,k}} + \boldsymbol{F_{vm,k}} \tag{2}$$

where u is the velocity, is the volume fraction, t is time, ρ is the density, p is the pressure, g is the gravity acceleration, $F_{S,k}$ is the surface tension force, $F_{D,k}$ is the drag force, $F_{vm,k}$ is the virtual mass force and the subscript k indicates the fluid phase. The Euler-Euler method was used to model the multiphase flow coupled with a Schiller-Naumann drag model. The open-source OpenFOAM v4.0 was used for the calculations.

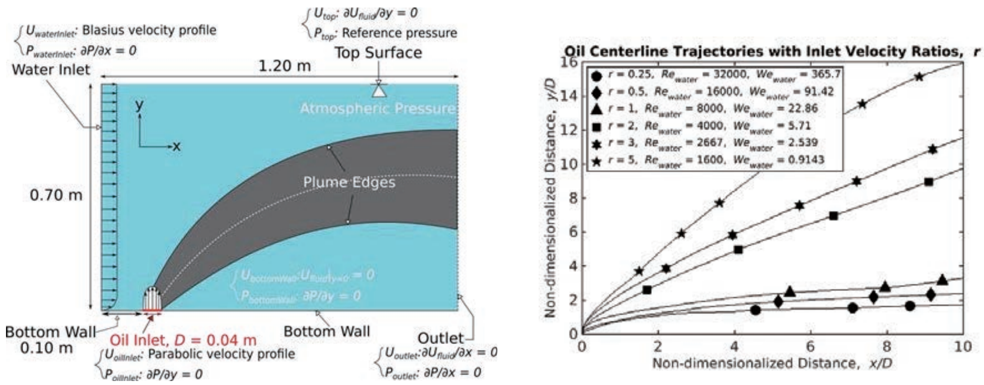

Figure 1: Schematics of oil jet in water crossflow including boundary conditions (left) and oil jet centerline trajectory for varying Re_{water}, We_{water}, and r (right).

3. Results and Discussion

The velocities and volume fraction were averaged for 30 seconds (from t = 10 - 40s). In Fig. 1b, the effect of varying the velocity ratio (r) on the oil plume trajectory. The distances are non-dimensionalized by the oil inlet diameter D. With the increase of Re_{water}, We_{water}, and r, the trajectories of the oil plumes centerlines were ascendant, while with lower r the plumes quickly became horizontal. These effects are highly dependent on the value of r, which seems to change the behavior of the plume in the interval $1 \leq r \leq 2$.

As the oil plume developed, the oil plume was caught in the effect of the vortexes near the inlet, which did not happen so strongly in the values with r above 2. This mechanism could explain the strong dependence of the plume centerline tendency according to the r ratio.

4. Conclusion

The effects of the oil jet in a crossflow were investigated using an Euler-Euler multiphase numerical method. The trajectory of the oil plume centerline was strongly affected by the ratio r between the oil inlet velocity and the water inlet velocity. Vortexes near the inlet could be a mechanism in favoring the faster horizontal trend of the plume trajectory of the instead of a faster plume ascendance. Techniques that could generate such a vortex near the well inlet could help in extending the residence time of oil in the deeper ocean which could enhance biodegradation. Further research is needed to investigate the jet in the crossflow phenomenon.

References

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