Numerical Simulation of Erosion-Corrosion in Four-Phase Flow

Benedetto Bozzini[1], Marco Ricotti[2], Ameriga Fanigliulo[1]

[1]INFM - Dipartimento di Ingegneria dell'Innovazione - Università di Lecce, v. Monteroni, 73100 Lecce, Italy
[2]Dipartimento di Ingegneria Nucleare - Politecnico di Milano, v. Ponzio 34/3, 20132 Milano, Italy

In this paper we address the problem of the simulation of erosion-corrosion phenomena in four-phase flows of relevance to the petrochemical industry. In off-shore crude-oil extraction systems, and pipes in particular, a four-phase flow typically develops in which two immiscible liquids are present (oil and seawater) together with a gaseous phase (a hydrocarbon mixture) and a solid particulate (sand). Scope of the study is the investigation of the erosion-corrosion of pipe walls, due to the internal flow of gas-liquid multiphase mixtures carrying an inert particulate solid phase.
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The analysis aims at the qualitative and quantitative evaluation of the corrosion effects enhanced by erosion at the walls of a pipe bend, into which a fluid mixture of two liquid phases plus a gas phase flows and transports a solid phase.

A computational fluid dynamic tool has been selected for the simulation of the flow field inside the piping and for the simulation of the particle trajectories and their impact on the bend walls. CFD is currently one of the more sophisticated and promising approaches for the analysis and solution of a wide class of problems involving flow domains and in a wide set of research and industrial application fields. CFD codes solve the full set of fluid dynamic balance equations, usually in Navier-Stokes formulation for momentum balance, taking into account for the fluid turbulence via different models. In particular, the code adopted for this study (FLUENT code) solves the balance equation set via a domain discretisation, using a control volume approach to convert the balance PDEs into algebraic equations solved numerically. The solution procedure integrates the balance equations over each control volume, thus obtaining discrete equations that conserve primary quantities on a control volume basis. The numerical solution defines the flow field quantities, used by other models than the fluid dynamic one, e.g. for phases transported by the generic fluid phase.
One of the more important features of this class of fluid dynamic codes, is to simulate complex fluid flows and geometric domains, both in 2-D and 3-D, accounting for turbulence of the flow fields. A set of models are usually made available to the user, different mainly in the scale of turbulence they can evaluate. The present case study has been performed by adopting a 3-D unstructured mesh (dimension: 10^5 hexahedral cells) for the pipe, an implicit method for the numerical solution of mass and momentum equations and a k-ε model for the turbulence. The mixture composition and phase velocities are defined at the inlet boundary.

A specialised model is used for the simulation of particles transported in the continuous flow field. The Discrete Phase Model (DPM) solves the equation of motion for a discrete phase dispersed in the continuous phase, by adopting a Lagrangian frame of coordinates and leading to the calculation of the particle trajectories. The force balance equation on the particle is solved using the local continuous phase conditions.

Moreover, in turbulent flows the effect of turbulence on the particle dispersion may play a significant role. A stochastic model, the Discrete Random Walk (DRW) model or "eddy lifetime" model, predicts the turbulent dispersion of particles by integrating the trajectory equations for each particle, by adopting the instantaneous fluid velocity along the particle path.

The model available in FLUENT code in order to calculate the erosion flux is a simplified model taking into account the mass flow rate of the impacting stream, the surface area of the impacted wall boundary cell) and an impact angle function. Physical parameters describing independent erosion and corrosion phenomena were derived from experiments. The synergistic effects were simulated numerically, a typical result of erosion-corrosion distribution is shown in the figure reported below.

Four fluid dynamic characteristic parameters have been selected as key points for the Case Matrix definition, namely:
1. Fluid Flow inlet velocity;
2. Inlet Volumetric Flow ratio for the Gas phase;
3. Inlet Volumetric Flow ratio for the Water (liquid) phase;
4. Mass Flow rate of inert particles injected.

Two values each have been selected to compose the 16 cases set; the values assumed by the parameters define a range sufficiently wide to cover a representative domain for the phenomena.