Preliminary Numerical Study on Oil Spilling from a DHT

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ABSTRACT

This paper reports a preliminary 3D numerical study of submerged oil spilling from a damaged Double Hull Tanker (DHT) using a VOF-based multiphase flow solver within the framework of the open-source CFD package OpenFOAM. In order to reflect the different features of two typical oil spilling scenarios, i.e. grounding and collision, two cases with spilling holes being located on the bottom and side wall of the DHT, respectively, are simulated. The numerical results are compared with the experimental data. Satisfactory agreements are achieved. The hydrodynamic features, particularly the role of the viscosity and turbulence effects, are discussed.

KEY WORDS: Oil spilling; Double Hull Tanker (DHT); OpenFOAM; VOF; multiphase flow.

INTRODUCTION

The oil spilling from damaged oil pipes or tankers has been recognised as a significant potential environmental impact and, therefore, attracts worldwide researchers’ attention, particularly following the recent incident in the Gulf of Mexico. The forefront of the research in this field mainly includes two aspects, i.e., the behaviour of spilled oil in the sea and the mechanism of oil spilling from damaged hull/pipe. The former benefits the prediction of the trajectory and/or fate of the spilled oil and, therefore, the decision to be made to prevent it from further dispersion (e.g., Vethamony, et al, 2007; Wang, et al, 2008). The latter is related to estimating possible accidental oil outflows. This paper focuses on the latter.

In practices, the Double Hull Tank (DHT) design has been regarded as the most effective way to minimize the oil pollution due to accidental vessel damages. This was first regulated in the Oil Pollution Act of 1990 (OPA-90) in the US congress and later has been executed for oil tanker design under the impetus of UN’s International Maritime Organization (IMO). In order to evaluate the performance of the DHTs in reducing environmental oil pollution during the collision and grounding incidents, IMO (1994) proposed a widely-used probabilistic approach, and this approach was revised and simplified by several studies (e.g., Michel et al 1996; Sirkar et al 1997; IMO, 2003; IMO, 2004a; IMO, 2004b; Smailys and Česnauskis, 2006) to overcome its complexity and restriction. According to the empirical data set of individual vessel incidents provided by the US Coast Guard from 2001 to 2008, Yip, et al (2011) claimed that DHTs were associated with smaller amounts of oil spillage than Single Hull Tankers (SHT). Although these aforementioned studies were able to provide some necessary information (e.g., ultimate amount of oil leakage) related to the tanker performance in accidental readings and collisions, they are mainly based on the steady/quasi-steady assumption ignoring the turbulence effects and, therefore, fail to explore the unsteady behaviour of oil spilling processes.

In fact, the oil spilling affects the loads on the oil tankers and thus their motion, which in turn affects the behaviour of the spilled oil. The systematic investigations in this field must consider the hydrodynamic features of three liquid phases, i.e., water, oil, and air, and must be regarded as an integrated system covering the external environment (tide, current and wave), the motion of the ship and the oil leakage. Therefore, it is a dynamics dominated process as mentioned by Karafiath (1992). Even in still water, experiments have confirmed that the hydrodynamic feature is significant in the cases with oil spilling from a fixed SHT (Lu, et al, 2010, Tavakoli, et al, 2011). It is worthy of detailed investigations to achieve better understanding of the hydrodynamic feature of the oil spilling from DHTs in order to contribute to future design of the DHTs. Both experimental and numerical studies have been found in the public domain. This paper performs numerical investigations and therefore only the review on the related numerical works is given below. The review on the experimental work can be found in Lu, et al, (2014).

In order to capture the hydrodynamic features, a multiphase numerical model based on Navier-Stokes equation is required. So far, two groups of numerical approaches have contributed to this issue. The first one is the finite volume method (FVM) incorporating with the Volume of Fluid (VOF) to capture the interface between different phases. By implementing this approach, Lu, et al (2010), Xiao, et al (2010), Krata, et al (2012) have numerically investigated the behaviour of the oil spilling from oil tankers. Another approach is a meshless method based on multiphase viscous model, e.g. the Moving Particle Semi-Implicit method (MPS) by Koshizuka and Oka (1996), Cheng, et al (2010) and PNU-MPS approach developed by Lee, et al (2011), which has been used to simulate oil spilling from two-dimensional (2D) damaged oil tanker.

It should be noted that the references cited above focused on the SHTs, the corresponding numerical studies related to DHTs are rarely seen in literature, partially due to the complexity caused by the narrow blast