Computational Modeling of Ballast Tanks to Improve Understanding and Maximize Effectiveness of Management Practices and Treatment Mechanisms - Extension of Laboratory Study

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Collaborators: FedNav, Inc. - Montreal, Canada

Project was completed in CY2007

Overview

To reduce the spread of nonindigenous aquatic species, large vessels with ballast tanks exchange coastal ballast water with mid-ocean seawater (referred to as “ballast water exchange” (BWE)), with a goal of 95% or greater volume replacement. Measuring the exchange efficiency (EE) on board operating ships is extremely difficult and subject to large variances. This project examined use of high-resolution computational fluid dynamics (CFD) to model ballast tank water flow and to predict EE for flow-through ballast water exchange, whereby seawater is pumped into the ballast tank, typically at the bottom of the tank using the normal ballast piping, and the tank is overflowed out the top hatches and/or vent and sounding tubes. IMO guidelines and U.S. Coast Guard regulations for flow-through exchange require the volume of incoming water be equal to or greater than 3 times the total volume of the ballast tank being exchanged. Theoretically this will achieve 95% volume replacement.

A 1/3 scale four-compartment physical model of sections of a bulk carrier ballast tank representative of those entering the Great Lakes was constructed to obtain experimental data to compare and validate CFD model predictions. Tank specification and blueprints were provided by Fednav Limited (Montreal, Quebec, Canada). Experiments were conducted in the 1/3-scale physical model for complete 3 tank volume exchanges. To mimic conditions of most concern to the North American Great Lakes, experiments used fluids representing both freshwater (FW) and brackish water (BrW; density equal to 20 ppt salinity) ballast being replaced by seawater (SW; salinity=35). Since the utilization of true ocean water was impractical, a solution of magnesium sulfate ($MgSO_4$) was used to simulate both BrW and SW to simplify the water preparation procedure and provide a stably stratified fluid interface. To match the index of refraction of the $MgSO_4$ solution and provide the desired density (g/kg) differences (ΔFW-BW $\cong$ ^{4}0.010 and ΔFW SW $\cong$ 0.025) between resident and influent fluids, ethanol was added to the FW initially in the tank. Experiments were performed for each of the two density differences using one or two experimental flow rates that scaled to the equivalent of ~1,012 gpm (230 m^3/hr) and ~1,700 gpm (386 m^3/hr) at full-scale.

Photos of flow-through ballast water exchange - deck perspectives

Transient, two-fluid CFD simulations were performed using the commercial viscous flow solver software ANSYS® FLUENT® to model the 1/3 scale physical model and to simulate exchange in a full scale bulk carrier ballast tank. Data from the 1/3 scale CFD four compartment model simulations are compared with the 1/3 scale experimental model data. Comparisons of the data within the tank are quite good. CFD predictions of EE show that CFD can predict the right trends and falls within the experimental error bands. Two full-scale CFD simulations were run to determine the CFD model’s sensitivity to relatively small structures (longitudinal stringers). The results show that these structures are very important to the physics of two-fluid mixing and lead to significant changes.

CFD modeling can be a very useful approach to understand ballast tank flow. The use of CFD model-based calculations of EE could be a practical alternative to on-board experiment.

Products

CFD Model Animations

- Full Size
- Four-cell (regular speed)
- Four-cell (slow motion)

Publications

Chang,III, PA, W. Wilson, J. Carneal, P. Atsavapranee, S. Verosto, D. Reid, and P. Jenkins. 2009. *Computational Modeling of Ballast Water Tanks to Improve Understanding and Maximize Effectiveness of Management Practices and Treatment Mechanisms, Phase II --- Extension of Laboratory Study (Final Report). NOAA Technical Memorandum GLERL-148*. National Oceanic and Atmospheric Administration, Great Lakes Environmental Research Laboratory, Ann Arbor MI and NSWCCD-50-TR-2009/028, Naval Surface Warfare Center Carderock Division, West Bethesda, MD, USA. 76 pp.

Wilson, W. P. Chang, S. Verosto, P. Atsavapranee, D.F. Reid and P.T. Jenkins. (2006). Computational and Experimental Analysis of Ballast Water Exchange. *Proceedings, ASNE Marine Environmental Engineering Technical Symposium (MEETS),* Jan 23-24, 2006, Arlington, VA.

Reid, D.F., S. Verosto, P. Chang, W. Wilson, P. Atsavapranee and P.T. Jenkins. 2005. Modeling of Ballast Water Mixing and Flow Dynamics to Understand Ballast Water Exchange. *Proceedings, ENSUS 2005: Marine Science and Technology for Environmental Sustainability*, April 13-15, 2005, Newcastle-Upon-Tyne, UK