Use of a Web-Based Virtual Laboratory to Introduce Mass Transfer Processes in Environmental Engineering and Science Courses

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Abstract:

This paper describes the development of a web-based laboratory as a means to introduce advanced mass transfer processes concepts in environmental engineering and science courses. This web-based laboratory is comprised of interactive user-friendly input interfaces, customizable output interfaces, illustrative Help and Tutorial sections, a relational database, and a finite element in space and finite difference in time numerical engine. Architecture used to develop and implement this system is briefly discussed.

The virtual laboratory employs spherical particles representative of a number of matrices of interest to environmental engineers, including water treatment systems and subsurface contaminant fate and transport. Users of the laboratory may define physical and chemical characteristics of up to five different particles, including up to five separate reactive regions within each particle. Complex mass transfer processes, including linear and nonlinear sorption and Fickian and non-Fickian diffusion processes, are capable of being modeled for each reactive domain within each particle. Two types of boundary conditions, reflective of completely mixed flow reactors and completely mixed batch reactors, are also included. Illustrations of the education benefits derived from use of the web-based laboratory are demonstrated by two examples.

Introduction

Understanding the complex processes controlling the mass distribution, transportation, reaction, and transformation of contaminants within the natural or engineered environment is critical for sustainable agricultural practices, water and wastewater treatment, and effective and efficient contaminant remediation. Communicating an understanding of the underlying concepts of mass transfer processes, however, has been a difficult challenge in civil and environmental engineering education [1]. While students may be well-grounded in the fundamental theories of mass transfer processes after completion of traditional coursework, they may not be as well prepared to transition to practicing engineering and conducting state-of-the-art research, because of the inability to apply known concepts to new problems, and the inability or reluctance to construct numerical models.

This paper describes the development of a virtual mass transfer processes laboratory (MTPL) as a means to introduce advanced mass transfer concepts in environmental engineering and science courses. Subsequent to this introduction, descriptions of the conceptual and numerical models of MTPL are presented. Following a brief presentation of the system architecture, system components are introduced. Illustrations of the educational benefits that may be derived from use of the web-based laboratory are then demonstrated by the presentation of two case studies.

Mass Transfer Processes Laboratory Conceptual Model

MTPL models mass transfer into and out of spherical particles in two types of ideal reactors: completely mixed flow reactors (CMFR) and completely mixed batch reactors (CMBR). Twelve different types of mass transfer conditions, corresponding to linear and nonlinear sorption with Fickian and/or non-Fickian diffusion processes, are coupled with different boundary conditions of the CMFR and CMBR. These problems are solved numerically by using finite element method in space and finite difference method in time. Up to five different types of particles, with up to five separate reactive domains in each particle, can be used in MTPL.

Mass Transfer Processes Laboratory System Architecture

This web-based laboratory is comprised of interactive user-friendly input interfaces, customizable output interfaces, illustrative Help and Tutorial sections, which are supported by a relational database, and a finite element in space and finite difference in time numerical engine. CORBA technology provides the connection between the numerical model and the web server. Figure 1 provides a general illustration of the MTPL system architecture.

Figure 1. Mass Transfer Processes Laboratory System Architecture.

Execution of virtual laboratory experiments is accomplished as follows. Users input data from a web browser such as Internet Explorer (Microsoft Corporation, Redmond, Washington); Tomcat web server [2] accepts the data and sends it to a database by Java Server Pages, which create Java Beans to hold and manage the information. Java Beans then initiate a simulation request, which is transferred by Common Object Request Broker Architecture (CORBA) to the numerical engine. Upon receipt of the simulation request, the numerical engine retrieves input data from the database, performs the simulation, and communicates results back to the database. After the completion of simulation, results in the form of tables and graphs are available as web pages displayed on user's web browsers, including Excel (Microsoft Corporation, Redmond, Washington) tables and graphs. Input and Output Interfaces and Help and Tutorial systems are each introduced in the following sections.

Input Interfaces

The objective of the input interface is to assist users in defining the mass transfer problem, followed by step-by-step instructions on data submission. A set of interactive input interface web pages are logically presented to lead users through the simulation process. Users are provided the opportunity to input project descriptions, define the reactor configuration, determine the number of particles in the system, select the mass transfer process, identify the particle properties, and select the format for the model output.

Output Interfaces

The purpose of the output interface is to provide users with well-organized and customizable simulation results, including meaningful graphs. A striking feature of the MTPL output system is the use of Excel (Microsoft Corporation, Redmond, Washington) to summarize and present results. MTPL embeds Excel spreadsheets into the web page, and groups the results in terms of graphs and data tables. Data tables provide detailed numerical modeling results, and can be copied, pasted, or directly exported from the on-line Excel table to local Excel files by simply clicking on a single button. Graphical outputs provide impressive visualizations of the simulation results in the form of line, radar, or pie graphs. The MTPL output system is very flexible in that simulation results can be selectively displayed for particular particles, shells, and locations in the particle (when applicable), and for more than one hundred time points by interactively changing data collection locations and times.

The first page of the output interface provides a general overview of simulation results in the form of a general report. Following the general results, detailed simulation results, including concentration, mass uptake and mass flux, are presented in forms of line, radar or pie graphs and data tables for user-defined times and locations.

Help and Tutorial Systems

MTPL Help and Tutorial modules are designed to (i) highlight basic mass transfer processes principles; (ii) provide guidance for successful navigation of the laboratory website; (iii) provide step-by-step instructions for full utilization of the laboratory; and (iv) present meaningful case study problems to enhance students' understanding of mass transfer processes.

The Help module provides general background information of the mass transfer processes laboratory, including model overview, objectives and methods, conceptual and mathematical models, and theories of diffusion processes. Users can access the MTPL Help module by clicking the on-screen Help button on each page, where they can then obtain detailed instructions on how to use to laboratory. Five Case study problems are incorporated into the MTPL Tutorial module as an effort to provide an in-depth explanation of diffusion and sorption behavior than can arise from different initial and boundary conditions, different particle size and properties, and different diffusion and sorption mechanisms.

Mass Transfer Processes Laboratory Case Studies

Use of MTPL in environmental engineering and science courses can assist in the introduction of mass transfer processes by promoting students' interests in the topic through improved visualization of abstract concepts. It can also provide students an opportunity for self-paced learning [3], and can save students time by not having to develop complex numerical modeling programs.

Figure 2. MTPL Example One: One Large Particle and One Small Particle in a CMBR.

Figure 2 and Figure 3 provide two examples of MTPL output that vividly demonstrate how MTPL can be considered an appealing tool in mass transfer processes education. Example 1 (Figure 2) examines the mass transfer behavior of one large particle and one small particle in a CMBR. At the very beginning of the simulation period, the small particle is void of contaminant, while the large particle possesses a large contaminant concentration. Over time, solute mass is transferred from the large particle, into the reactor fluid, and then into the smaller particle. Example 2 (Figure 3) compares mass transfer behavior of a one-shell homogeneous particle with a five-shell heterogeneous particle in a CMFR. Numerous other instructive case studies are provided as part of the MTPL Tutorial module. Of course, instructors and users may create an infinite number of other mass transfer processes scenarios, either as part of formal instruction, laboratory exercises, or homework.

Figure 3. MTPL Example Two: Comparison of a One-Shell Particle with a Five-Shell Particle in a CMFR.

Summary

The virtual mass transfer processes laboratory provides students the opportunity to explore complex, highly nonlinear mass transfer processes in depth without having to create extensive numerical programs. Students can interactively input data from any location at any time, and then execute a real time simulation of the model based on that data, and provide user-defined results in the desired form. The system architecture created for this laboratory provides the necessary knowledge base to link high-level computer programs into a user-friendly web-based environment. The mass transfer processes laboratory may be accessed at the web address: <http://ceeserver1.vuse.vanderbilt.edu:8080/diffuion>.

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