The Transport Phenomena Course Teaching Strategies using Comsol Simulation Apps for Engineers and Scientists

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Abstract

Teaching undergraduate transport phenomena fundamentals course in universities worldwide was mainly based on the well-known most useful chemical engineering textbook ever written by Bird, Stewart and Lightfoot, (BSL, 1960). Students in recent years are motivated by real-life examples, but they have limited time to investigate the physics beyond them. This research paper presents the enhanced teaching methods used to introduce undergraduates to Comsol Multiphysics Apps solving research projects. The learning goal is achieved by going through sequent teaching approaches. Normally, the students learn to solve problems in their textbooks analytically and learn to validate their solution with the available numerical techniques. Progressing into solving more complicated 2D problems is a result of building the validation confidence with computer programs that develops students to go beyond their textbooks by removing assumptions. This approach is illustrated in details using the feature of App building; where changes and optimization can be implemented to show the breadth of analysis techniques. Students gain better insight into the interaction between realistic system design geometries, and the role of various Multiphysics. From an educational perspective, students in different engineering and science disciplines can now solve complex problems in a relatively short period of time, which provides new opportunities for strengthening their technical skills. One key result is an acceleration of their development as technologists, which allows them to ultimately provide greater business impact and leadership in their chosen career.

Keywords: Transport Phenomena, Multiphysics, COMSOL Application builder.

Introduction

Transport phenomena is considered one of the major courses in Multiphysics education, which is applicable in many areas of science such as chemical engineering, mechanical engineering, biomedical engineering, physics science and any other fields deal with more than one physics. Teaching this course was mainly based on the well-known most useful chemical engineering textbook ever written by Bird, Stewart and Lightfoot [2]. This book is covering three main parts of the transport phenomena field, where the first part is about "Momentum Transport" , in other words the field of Fluid mechanics properties such as velocity, pressure, viscosity , fluid flow nature and etcetera. The second part is dealing with another physics which is "Energy Transport". This part is investigating the heat transfer phenomena properties such as thermal conductivity, temperature distribution, energy balances and etcetera. The third part is delivering the Mass transport physics terms such as diffusivity, concentration distributions, multicomponent systems.

A transport phenomena course was offered at University of Regina for graduate level and then was taught to undergraduate level at Al-Mergib University deals with fundamentals of transport, such as Newton law, and reactive transport, such as Fick's law coupled with species transport laws. The course addresses students with little or no modeling experience and skills. Here we present the course concept as well as our experiences. There are two main goals. The first goal is to familiarize students with the basic concepts and phenomena of the subject. For that purpose, simple models are set up and examined by the students, hands-on the computer.

The old fashion of teaching this course for undergraduate students was going through simple mathematical hand derivation analysis with limited ability to reach the clear and visual results unless the students perform complex coding using one of the programming languages. Ending up at this point will require advanced numerical techniques education which is usually delivered in the graduate level.
The transport phenomena course is generally divided in two parts, the first part dealing with diffusive transport and the second part is covering the convective transport [1].

Using COMSOL Multiphysics modeling and simulation tools were as a mean of education for transport phenomena course. Newer versions with loaded advanced APP-builder feature allowed us as educators to create teaching apps in this course as well as other mentioned engineering and science courses.
This work will show brief examples of using the apps in teaching many case studies in transport phenomena course and how students can easily navigate through them and explore the visualized results.

Sample of Transport Phenomena APPS "Case Studies"

Image (1) shows a snapshot of a COMSOL APP used to solve diluted species transport / falling film design problem. In this problem, there are two physics involved in controlling the outcomes, and students can enter range of physical values the input data APP section and thus they will get wide range of scenarios.

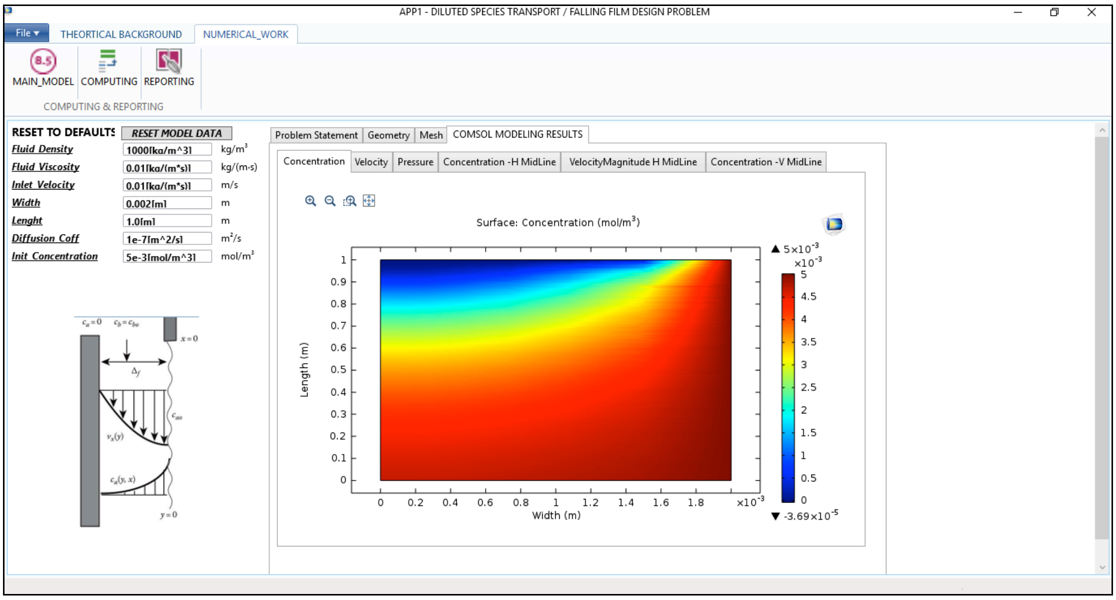

Figure 1: APP-1 snapshot - Solving diluted species transport / falling film design problem

The second image (2) displays the diluted species transport / turbulent flow design problem APP which can be used to investigate the effect of turbulent flow in distributing the fluid concentration. In the image snapshot, we see an example of one result for pressure contour inside the problem domain.

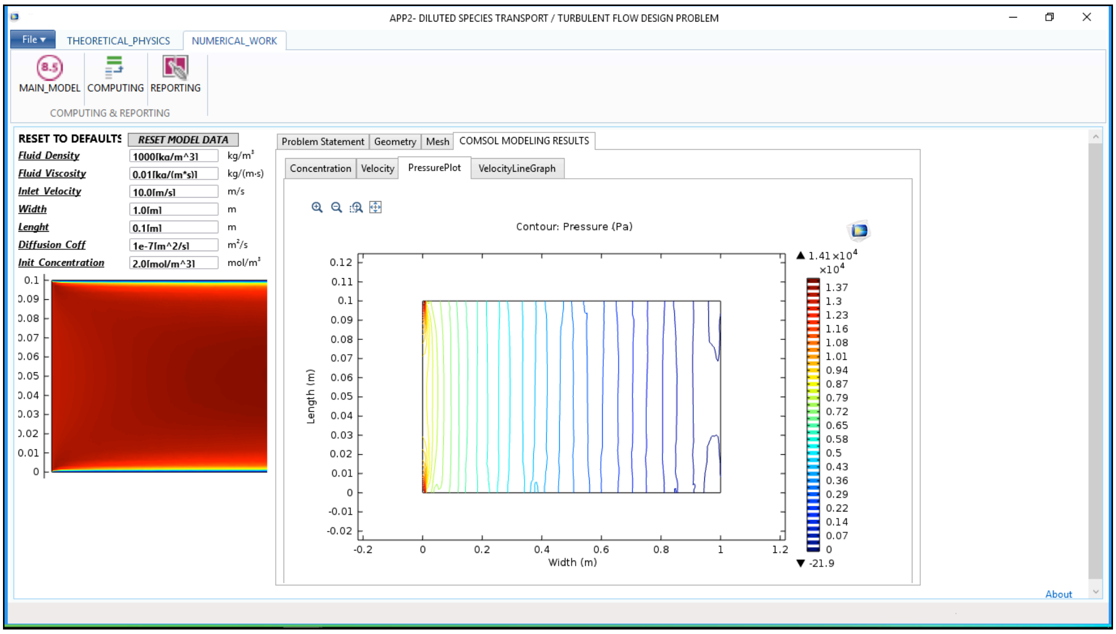

Figure 2: APP-2 snapshot – Solving diluted species transport / turbulent flow design problem

The third sample of using COMSOL APPS in transport phenomena course is shown in figure 3 which studies diluted species transport / laminar flow design problem.an expanded investigation was designed in this APP to cover in details all the possible outcome profiles at different positions.

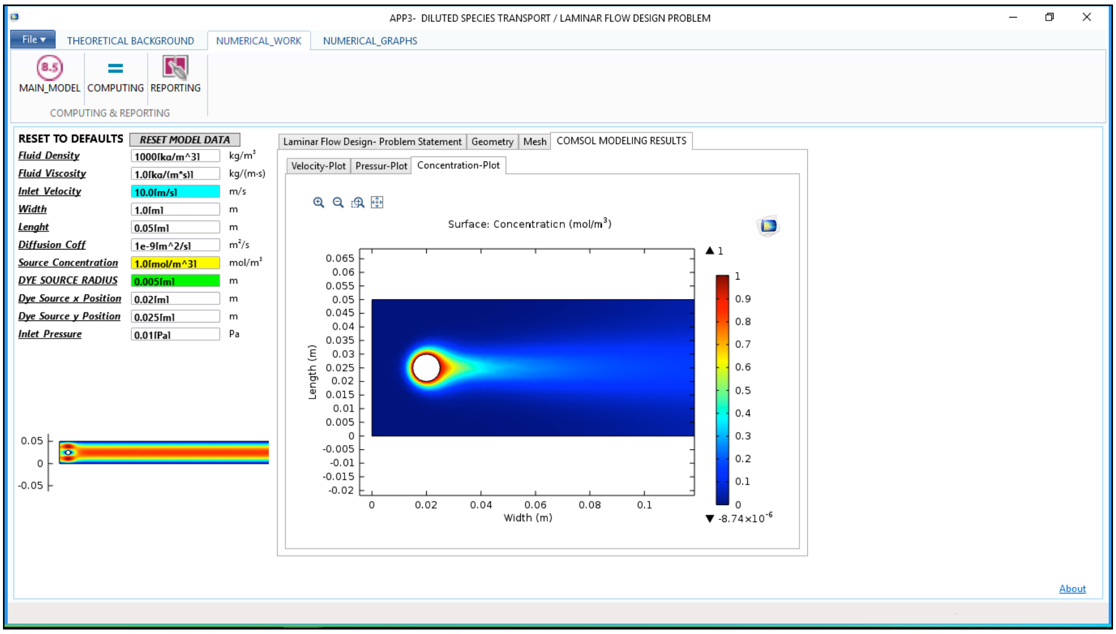

Figure 3: APP-3 snapshot - Studying diluted species transport / laminar flow design problem

APP-3 Navigation

APP number-3 was chosen to describe all the navigation steps in a brief student manual. The APP was organized in three main drop down ribbons as follow (see Figure 4).

Figure 4: APP-3 Main navigation ribbons

1. Theoretical back ground ribbon: where all the governing equations were outlined in two tabs one for laminar flow physics and the second one for transport diluted species. This ribbon will allow the students learn about the fundamentals used to build the solving model.
2. Numerical Work ribbon: We see all the numerical procedures are distributed in tabs (geometry, meshing, velocity plot, pressure contours, concentration plot).in addition, the students will be able to perform computing and reporting buttons so they can extract their results to a final technical report.
3. Numerical Graphs (Outcome graphs). This ribbon sows in details all the visualized results for (velocity profiles, concentration profiles, Pressure profiles)

Navigating and using the APP outcomes “Results of the 1st study APP-3”

Controlling the problem inputs must be done in “Numerical Work” ribbon where we see the default data are displayed in the main window at the left side (Figure 5). If the students change these data, they will get new scenario outcomes. For example, scenario#1 for default data will produce 5 velocity graphs, 5 concentration graphs and 5 pressure graphs and they can export the graphs data to other CSV or text softwares such as MS Excel and this will allow them to perform further analysis with other data sources such as experimental data collections.

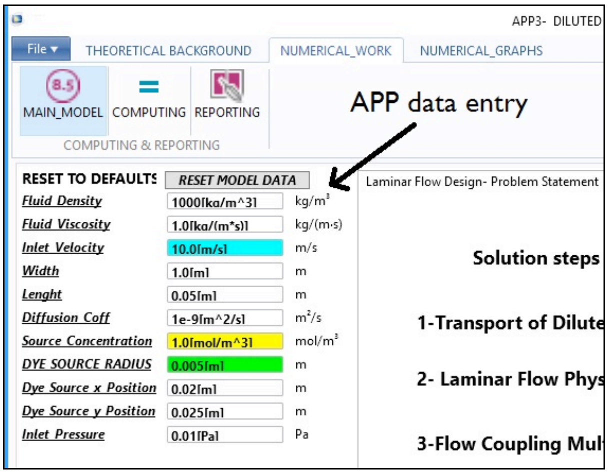

Figure 5: APP-3 data entry section

First scenario input “default’ data:
The app is designed to show series of input data as shown below in Figure 6.

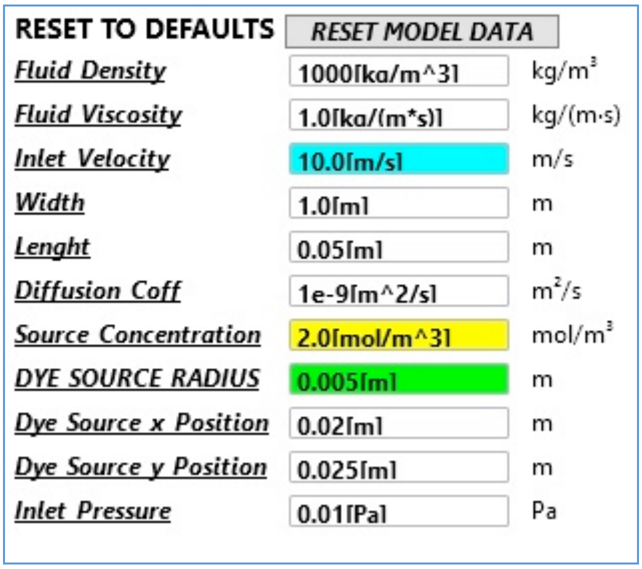

Figure 6: APP-3 Default input data panel

To start navigating the results of this scenario students must run the “computing” command to execute all the background numerical analysis. Once the computing process is finished a completion sound will indicate that. The Figures 7, 8,9 & 10 show the visualized plots for the mashing, velocity magnitude, pressure contours and concertation gradient around the dye source.

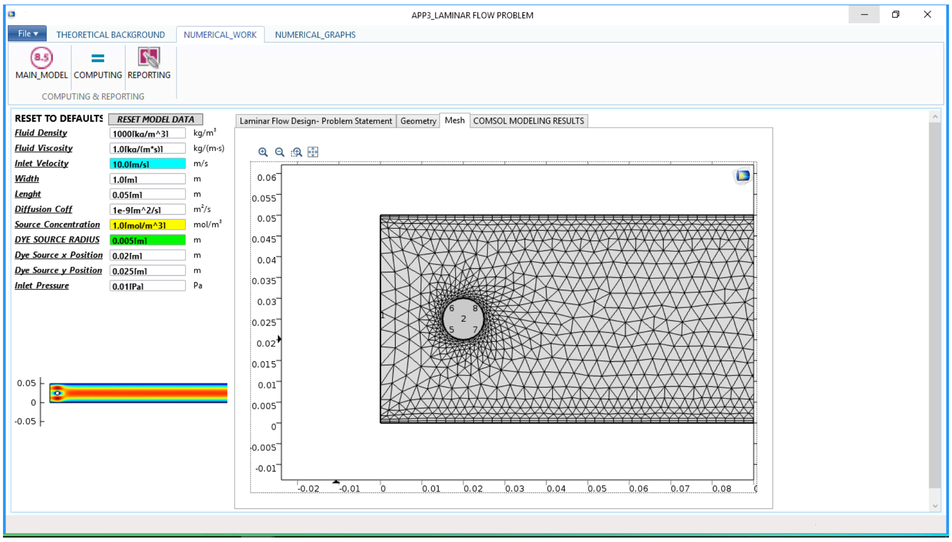

Figure 7: APP-3 Meshing organization inside the main domain

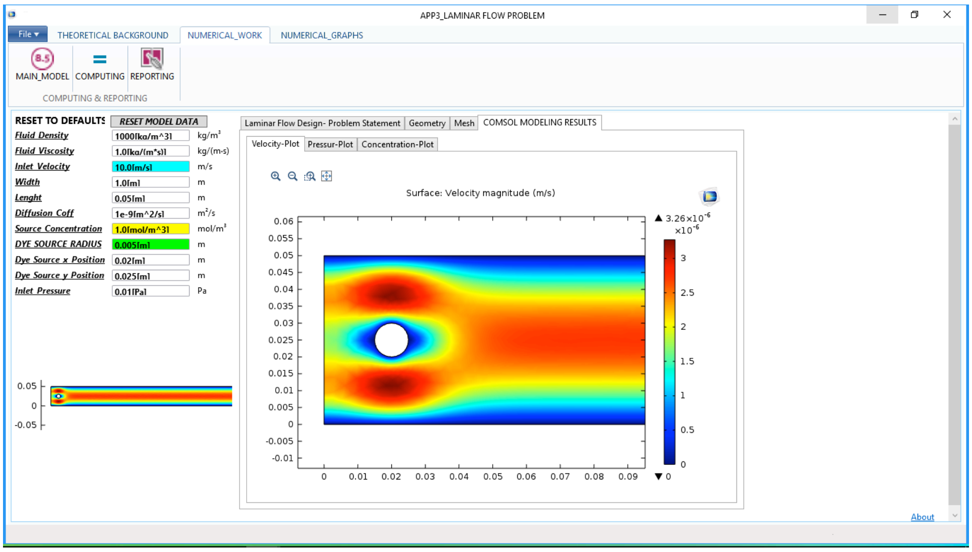

Figure 8: APP-3 Velocity magnitude colored plot

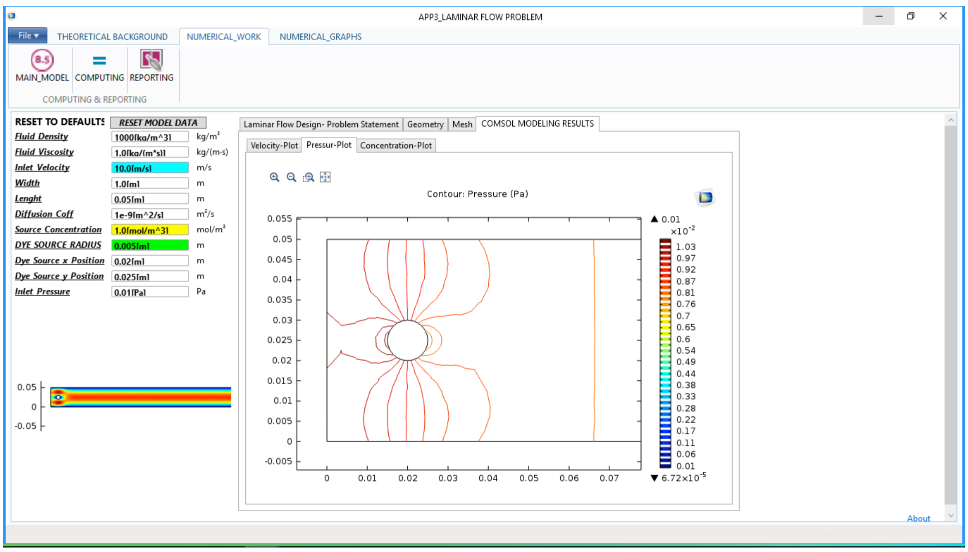

Figure 9: APP-3 Pressure contours around the dye source

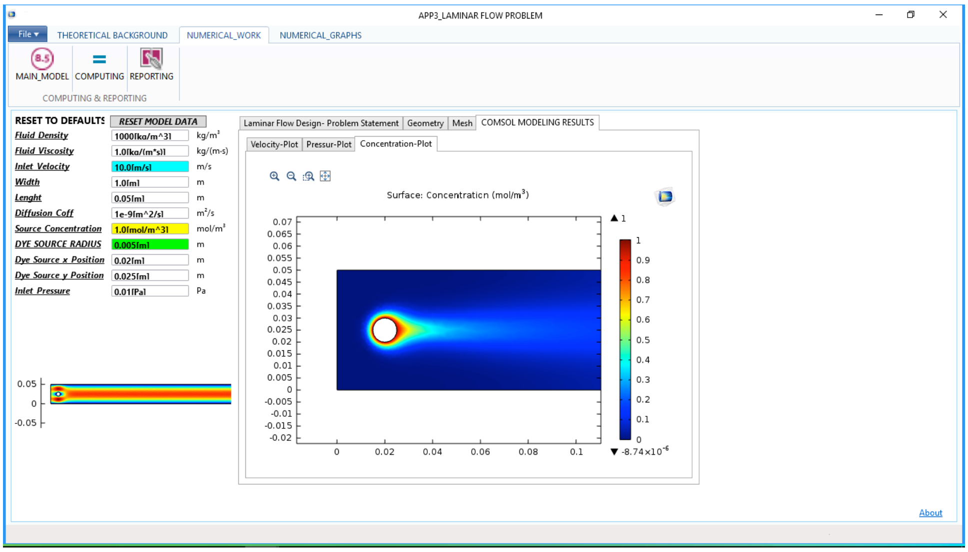

Figure 10: APP-3 Concentration visualized gradient around the dye source

To examine all these outcome profiles in details, students should go to the third ribbon "Numerical Graphs" where proposed four vertical cut lines across the domain as follow (see Figure 11 for illustration):

- 1st cut line at (0.02m)
- 2nd cut lint at DYE source X position + 0.01m
- 3rd cut lint at DYE source X position + 0.015m
- 4th cut lint at DYE source X position + 0.025m

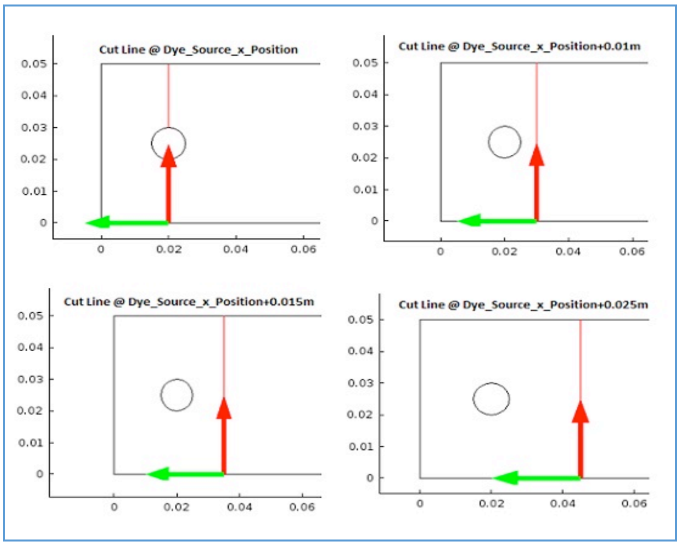

Figure 11: APP-3 Proposed cut-lines for in-details outcomes investigation

For each of the outcomes the app will produce four graphs and one collective graph for all cut lines to display the profiles development as the flow runs away from the dye source position. Figures 12,13 and 14 show the collective graphs for velocity, concentration and pressure profiles at four vertical cut lines.

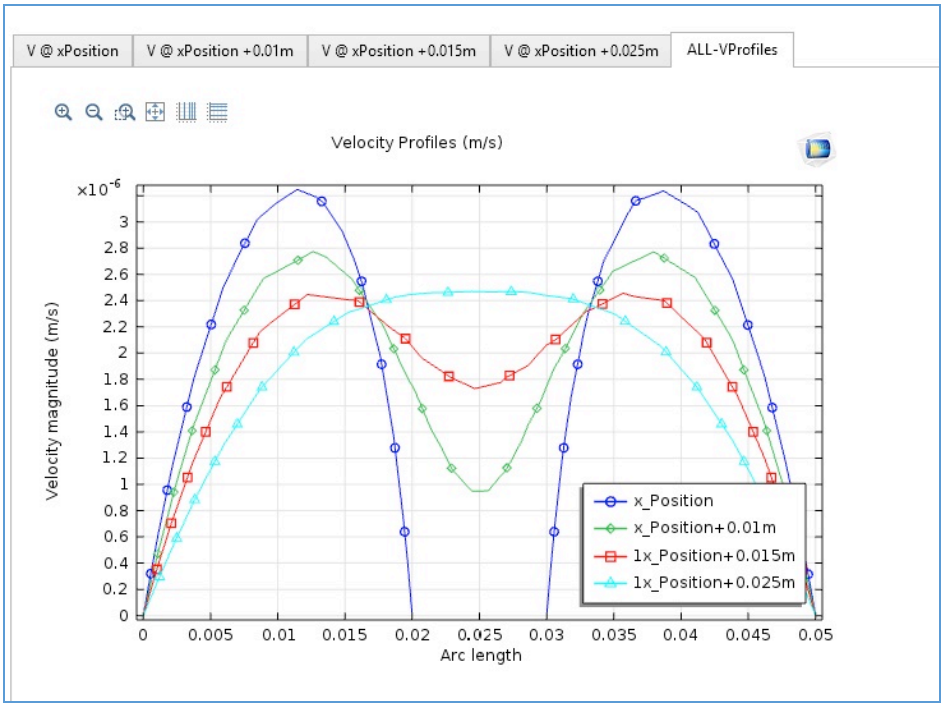

Figure 12: APP-3 Collective graph for velocity profiles at proposed cut-lines

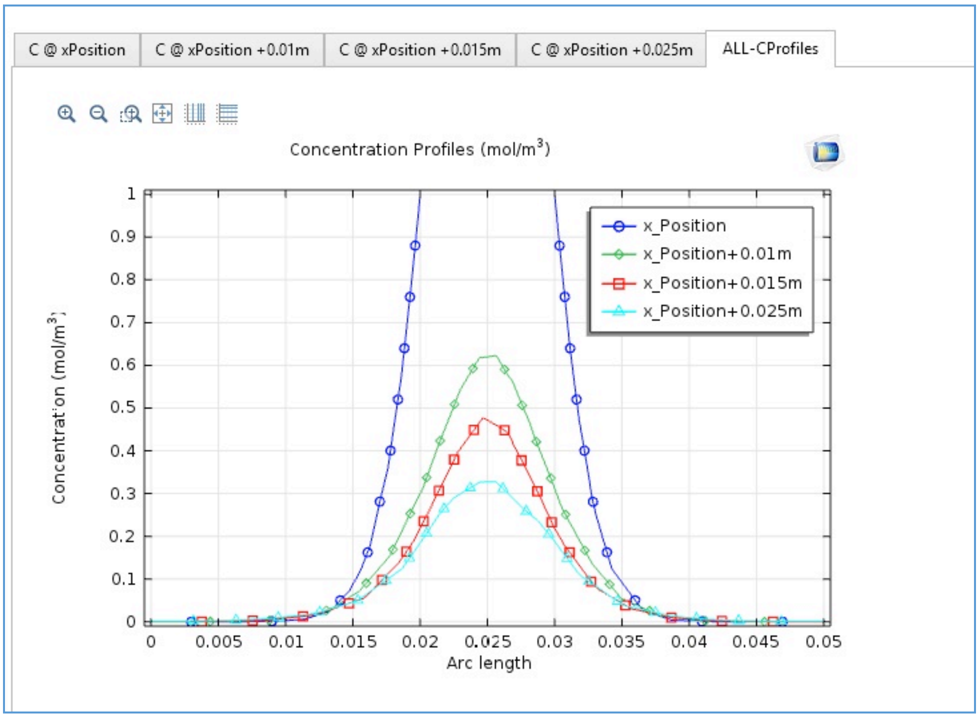

Figure 13: APP-3 Collective graph for Concentration profiles at proposed cut-lines

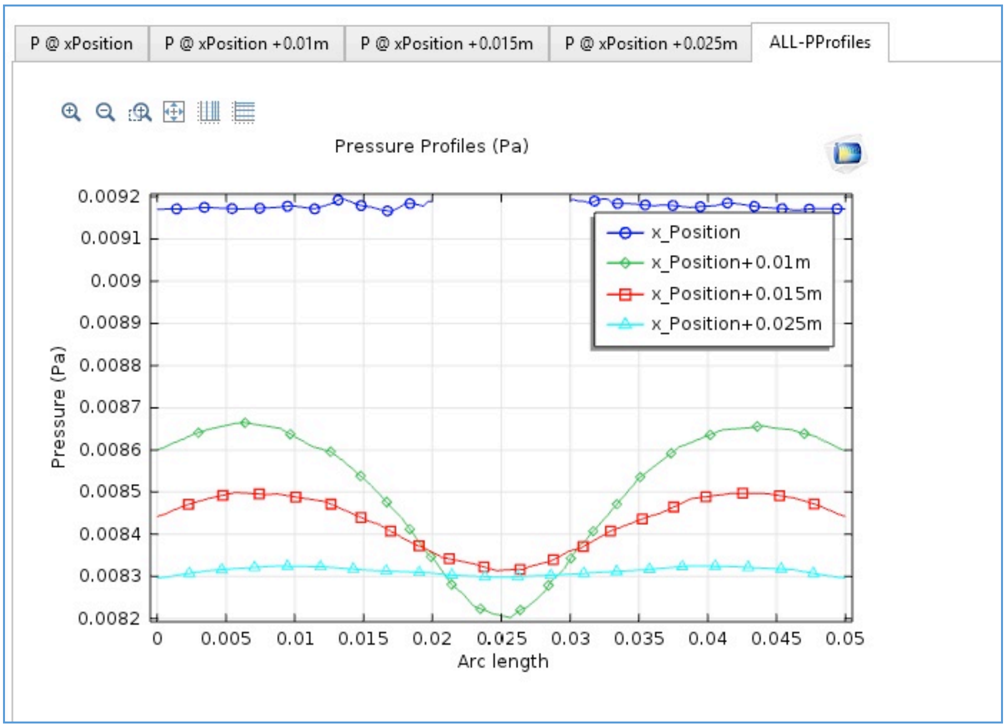

Figure 14: APP-3 Collective graph for pressure profiles at proposed cut-lines

Comparison of two case study scenarios

As discussed in previous section, the APP can produce different scenarios once the students change the input data values. In this paper, we will discuss only one change in the input values, which is the dye source radius (changed from 0.005m to 0.008m). By applying this change, we will get a new set of results for velocity, concentration and pressure profiles. Since the APP has an "Export" feature, all the individual graphs can be extracted to a data files where can be used in MS excel for further analysis.

A sample comparison between the default input data results with the new scenario outcomes is displayed in Figures 15 to 20. Note that this sample is only for two cut lines (Dye source X position + 0.01m) and (Dye source X position + 0.01m).

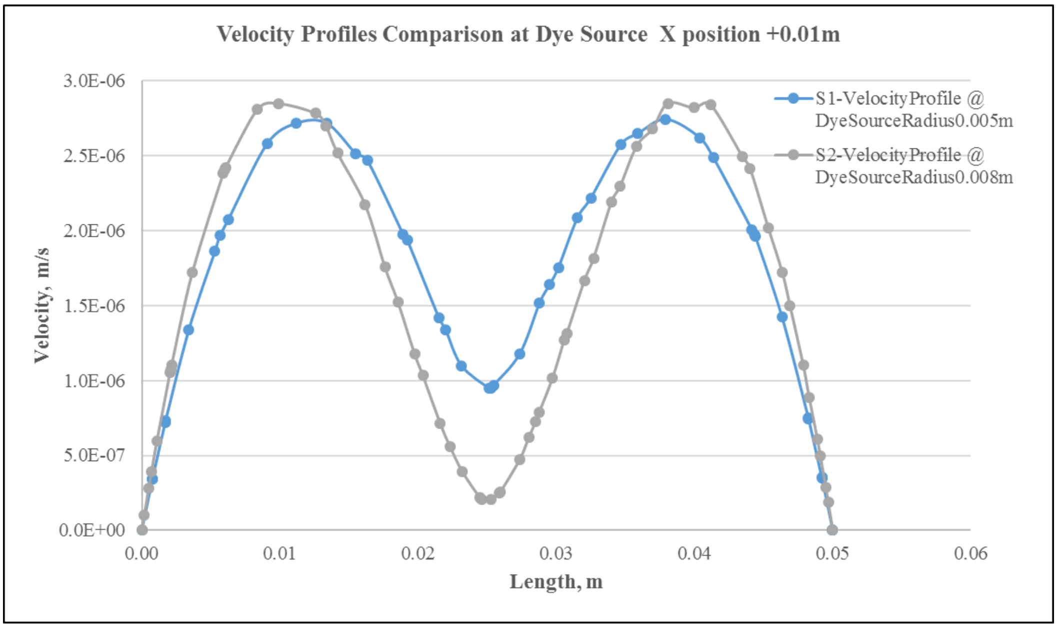

Figure 15: Velocity profiles comparison at proposed cut-line (Dye source X position + 0.01m)

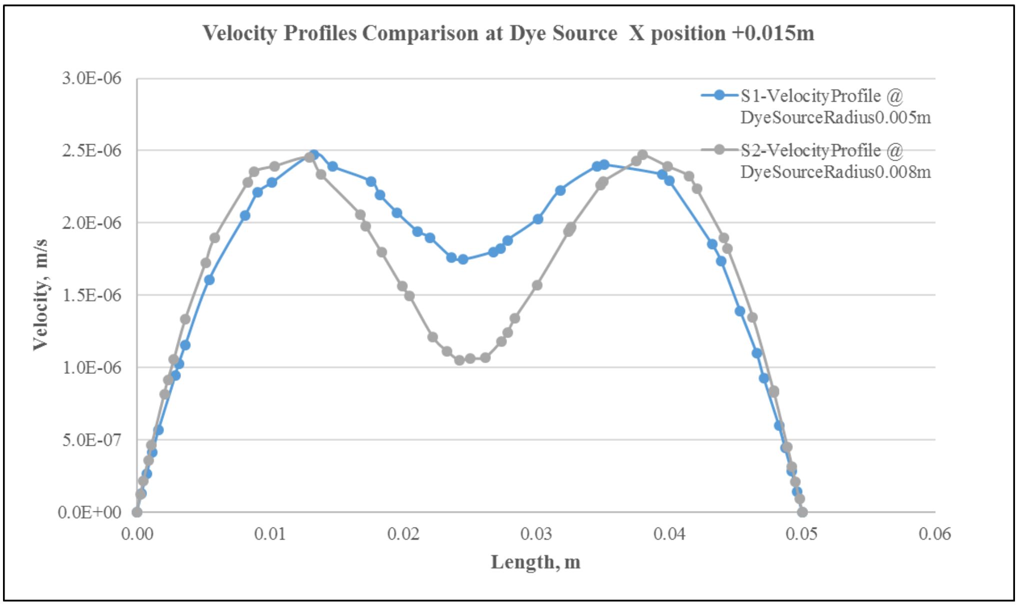

Figure 16: Velocity profiles comparison at proposed cut-line (Dye source X position + 0.015m)

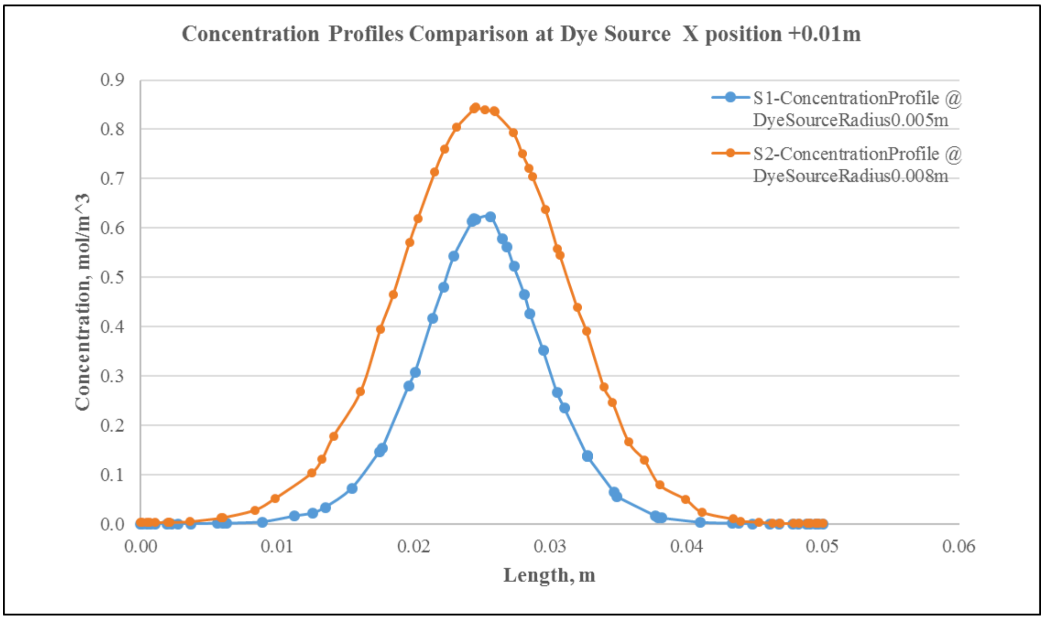

Figure 17: Concentration profiles comparison at proposed cut-line (Dye source X position + 0.01m)

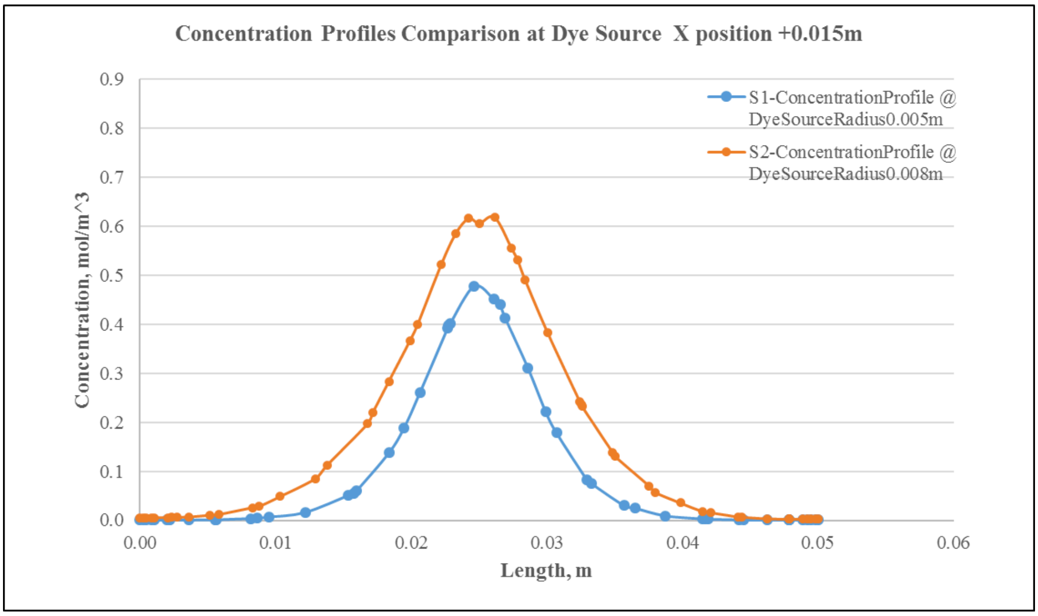

Figure 18: Concentration profiles comparison at proposed cut-line (Dye source X position + 0.015m)

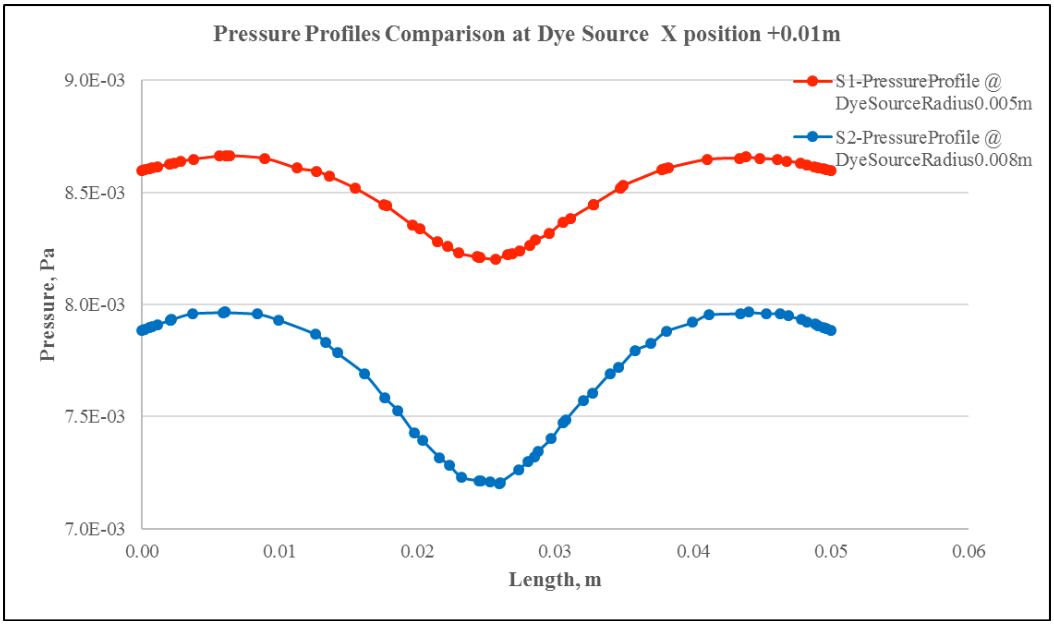

Figure 19: Pressure profiles comparison at proposed cut-line (Dye source X position + 0.01m)

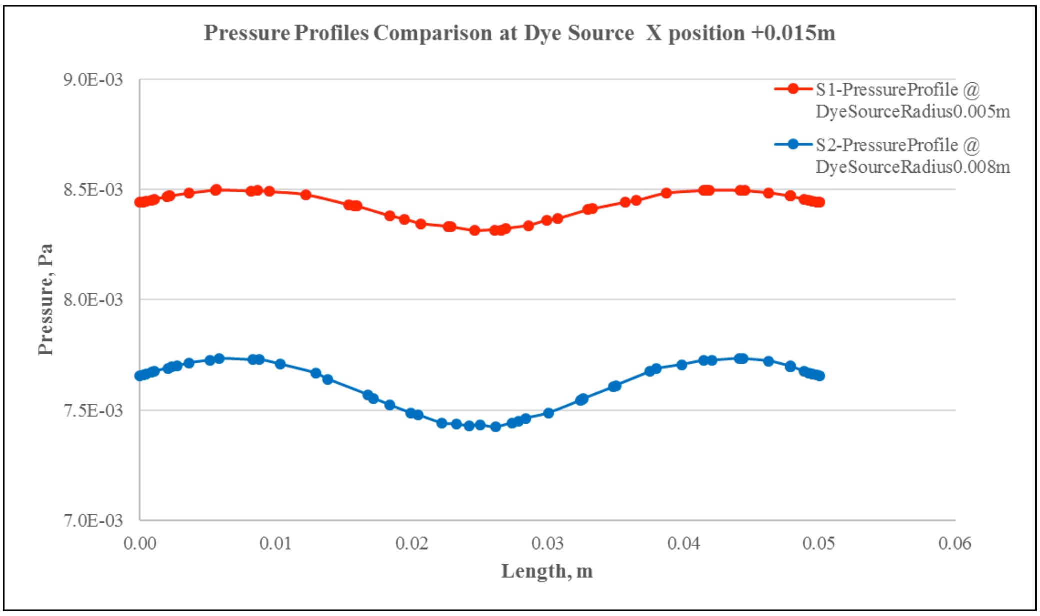

Figure 20: Pressure profiles comparison at proposed cut-line (Dye source X position + 0.015m)

Conclusion

COMSOL simulation APPS were created to cover the transport phenomena course. The APPS were developed to allow students review, investigate, analyze and apply as many case studies as they want. Subsequently, this technique will advance their vision and understanding of the topics. Visualized results in the APPS are changeable once the student control the input data. These results can be exported to be used in other packages such as MS Excel where they can collect all results for further analysis.
This APP builder feature was added to the regular COMSOL package to allow educators enhance the teaching approach and as result this will develop students deeper understanding for the course.

Acknowledgments

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