

# Enhancing Student Learning in Thermal-fluid Sciences Courses Through Software

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## ABSTRACT

Computer software has been used widely in engineering education, and one outcome of engineering education is the ability to use modern software in the related field. This paper will discuss the use of three software packages in thermal-fluid science courses for mechanical engineering technology students. The software packages discussed in this paper are Automation Studio for fluid power, EES for thermodynamics and energy conservation systems, and molecular dynamics software for thermodynamics. Each of these packages has a different purpose in the classroom.

Automation Studio is a powerful simulation package that can be used to model hydraulic and pneumatic circuits, as well as electrical, logic and other control circuits. Students use this in the lab portion of fluid power to simulate hydraulic and pneumatics circuits, helping them to visualize what the circuit does. They follow up by building the circuit to see if it achieves desired operation. The EES software is a calculation package similar to MathCad which is designed to simplify thermodynamic calculations by including built in property tables, and other topic specific features. Students use this to find thermodynamics properties instead of using property tables. They can also set up thermodynamic problems with the necessary material properties available within the program. The third software package discussed in this paper is a molecular dynamics software simulation. Students do not learn how to use the program, but the graphic outputs from the program can help them to better understand certain thermodynamics concepts from a microscopic view.

## INTRODUCTION

Computer software has been used widely in engineering education, and one outcome of engineering education is the ability to use modern software in the related field. This paper will discuss the use of three software packages in thermal-fluid science courses for mechanical engineering technology students. The software packages discussed in this paper are Automation Studio for fluid power, EES for thermodynamics and energy conservation systems, and molecular dynamics software for thermodynamics. Each of these packages has a different purpose in the classroom.

## AUTOMATION STUDIO

The textbook used in fluid power is “Fluid Power with Applications” [1], including an Automation Studio CD which contains simulations and animations of hydraulic and pneumatics circuits presented in the book. One objective of fluid power for mechanical engineering technology students is to design hydraulic circuits and pneumatics circuits. To enhance students learning, Automation Studio is introduced to students. Automation Studio is a powerful simulation package that can be used to model hydraulic and pneumatic circuits, as well as electrical, logic and other control circuits. Students use this in the lab portion of fluid power to simulate hydraulic and pneumatics circuits, helping them to visualize what the circuit does. For pneumatics, they follow up by building the pneumatics circuit to see if it achieves desired operation. The lab manual includes learning objectives, circuit operation and deliverables. In the circuit operation, a real industry example is provided and students need to build a circuit to solve this problem. By adopting the problem-based learning, students can find the connection between the lab problem and real world problem. Thus they are motivated to solve the problem.

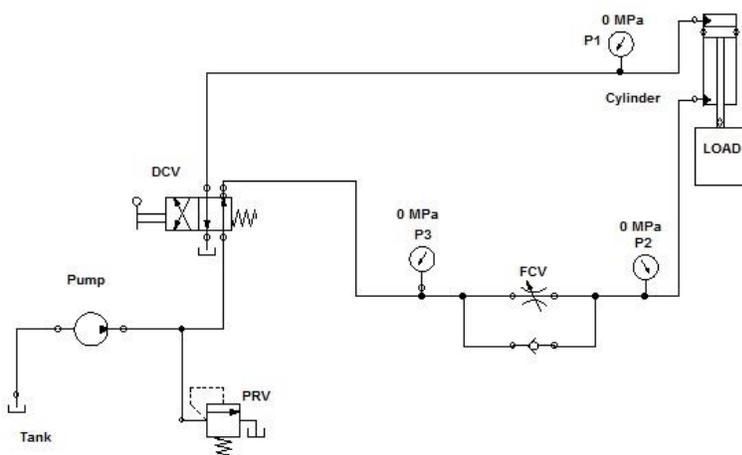


Figure 1. A meter out hydraulic circuit.

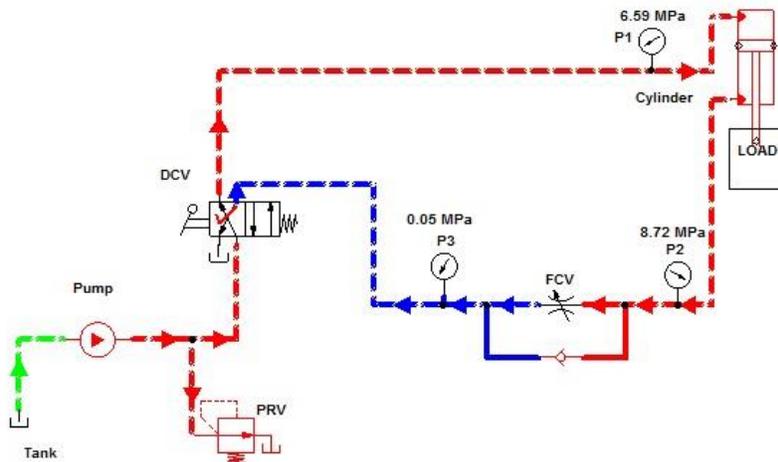


Figure 2. Simulation of the meter out hydraulic circuit.

One important benefit of using Automation Studio is that students can visualize what the circuit does. In fluid power, students often struggle with the relation between the position of the direction control valve (DCV) and the direction of the piston movement. With the help of Automation Studio, students can easily visualize what the circuit does and they can concentrate on learning the physical principles. Figure 1 shows a meter out hydraulic circuit. Figure 2 shows the simulation of this circuit when the DCV is actuated. Fluid gets out of the pump, goes through the DCV, enters the cap end of the hydraulic cylinder, and piston extends.

Another important feature of the Automation Studio is that the cylinder geometry, external loads, and fluid properties can be configured based on the hydraulic system to be simulated. In the simulation mode, pressure, velocity and volumetric flow rate can be monitored. Also high pressure hydraulic pipelines are shown in red and low pressure pipelines are shown in blue. In Figure 2, before entering the flow control valve (FCV), fluid is at a high pressure. The pressure at the rod end of the cylinder is 8.72 MPa, which is higher than the cap end pressure of 6.59 MPa. Except building the circuit and running the simulation, a majority of the lab deliverable is to explain the simulation results, such as piston speed, volumetric flow rate and pressure. Students can apply the physical principles they learned in class to explain the simulation results. Students are highly motivated to solve the lab problems compared to solve a homework problem. There are several reasons for this. Firstly, they build the circuit and run the simulations. They are very familiar with how the hydraulic circuit works. When they solve a homework problem in the textbook, sometimes they get lost in understanding the working principle of the hydraulic circuit. Secondly, in lab students work in group of three, which provide students an important opportunity to practice teamwork skills. In this small group setting, students are motivated to solve problems and improve their communication skills.

In fluid power, students need to learn lots of components used in hydraulic circuits, such as flow control valve, sequence valve, and counterbalance valve. Using Automation Studio to build the circuit and simulate the circuit helps students to reduce or eliminate confusion of the function of the components.

Designing pneumatics circuits is an overwhelming task for students. In lab, students first use Automation Studio to build a pneumatics circuit, then run simulation to observe how the circuit works. For an incomplete circuit, this program can still simulate the incomplete circuit, showing the location of high pressure and low pressure. This function helps students to design a pneumatics circuit using the step by step approach. Without the dynamics and visual interaction of the software, it is very difficult for students to learn the design of pneumatics. After students succeed in designing and simulating the pneumatics circuit, they follow up by building the pneumatics circuit to see if it achieves desired operation. Since they know the circuit they are building works in simulation, they are more confident in building the circuit.

One outcome of engineering education is the ability to use modern software in the related field. Students increased their software learning ability by learning Automation Studio in the lab. At the beginning of the semester, they learn the online tutorials which are intuitive and easy to follow. In the lab they start to build simple circuit and then move on build difficult circuit. At the end of the semester, they are all very familiar with this software. The summary of student feedback about Automation Studio is overwhelming positive. They are all very pleased to master a modern software used in industry. They think they understand physical principles in fluid power more thoroughly with the help of this software. A formal assessment of the effect of this software will be performed in the future.

## **EES**

Engineering equation solver (EES) is a software package which is designed to simplify thermodynamic calculations by including built in property tables, and other topic specific features. The text book, Introduction to Thermodynamics and Heat Transfer, includes a limited academic version of EES, which can be installed on computers. Students have chance to use EES in two courses. The first one is thermodynamics. One important objective in thermodynamics is to learn to find a state from two properties using the property table. The commonly used properties are temperature, pressure, quality, specific volume, specific internal energy and specific enthalpy. Students need to spend lots of effort to learn how to use the property table. EES can easily provide the property from two independent, intensive properties, which is the state postulate. For example, the specific internal energy of steam at 400 KPa and specific volume of  $0.40888 \text{ m}^3/\text{kg}$  can be determined using one simple EES command:

```
u1=intenergy(steam, p=400 [kPa], v=0.40888 [m^3/kg])
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Without EES, in hand calculation students first need to check the pressure table of saturated water to find the specific volume of saturated liquid  $v_f$  and saturated vapor  $v_g$ . Then use  $v$ ,  $v_f$  and  $v_g$  to calculate the quality of the steam. The last step is to use the specific internal energy of saturated liquid  $u_f$ , saturated vapor  $u_g$  and the quality to calculate the specific internal energy. It is obvious that using EES is straight forward and fast in finding the properties. From students' perspective, learning to use property tables can be very difficult. They need to go through a lengthy process of finding properties from the property tables, calculating mathematics equations and deciding the phase of the state. Any error during this process will result in a wrong answer. Students can compare their calculation with EES. This comparison provides guidance for students. If the student didn't get the correct result, they can go through their procedure to identify which part caused the error. Also EES makes understanding the state postulate easier. In thermodynamics, extra credit is offered to encourage students to compare their result with EES. This extra credit has a very low weight on the whole grade. In the fall 2014, one third of students made an effort to use EES to earn the extra credit. Their grades are higher than the class average which means using EES helps them to master thermodynamics. In the future, a formal assessment about the effectiveness of using EES on learning thermodynamics will be conducted.

The other course is energy conservation systems. In this course students learn to analyze Rankine cycle and refrigeration cycle. The Rankine cycle with reheat and regenerative can has as many as nine different states. The two stage cascade refrigeration cycle has eight states and the two stage refrigeration cycle has nine states. In order to analyze the system performance, the first step is to determine the enthalpy at all the states, which is very time consuming. The main objective of the course for students is to apply relevant physical laws, mainly energy conservation, and to understand how to improve the system performance. EES is perfect solution for this dilemma. Students can find enthalpy easily using EES and they need to understand energy conservation to write the equations in EES. Also it is easy to make changes in EES. After changing the equations in EES, all the equations will be solved and the result will updated. In hand calculations changing one parameter usually means resolving the problem again, very time consuming. In this course, projects are assigned for students to use EES to solve.

The survey to students about EES show that EES is easy to use, it provides a guidance for students to learn property of substance, and it saves time when solve complex thermodynamics cycle problems.

## **MOLECULAR DYNAMICS**

In thermodynamics, one difficult topic for students to understand is water vapor. In our daily life, we are very familiar with liquid water. But water vapor is invisible. The dew on the surface of a cold soda can, the cloud in the sky, and the steam from boiling water, they are all water

liquid droplets condensed from water vapor. From the microscopic view, students can easily visualize water vapor. The instructor uses molecular dynamics, which is a computer simulation technique of physical movements of atoms and molecules, to show students the water vapor from a microscopic view. A set of initial conditions, includes initial locations and velocities, are specified, as well as interaction potential among the particles. When the system reaches equilibrium, the thermodynamics properties such as density can be calculated from the water molecule locations. A water column inside air is simulated at different temperatures. All simulations are performed using LAMMPS [2]. Periodical boundary conditions applied in all directions.

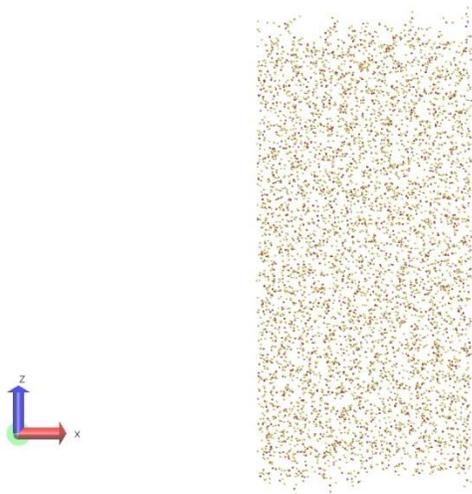


Figure 3. Snapshot of water molecules equilibrated in air.

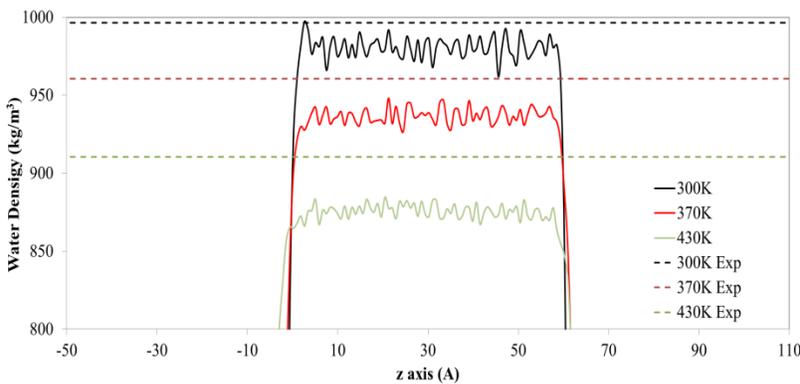


Figure 4. Comparison of saturated liquid water density calculated from molecular dynamics with experimental results.

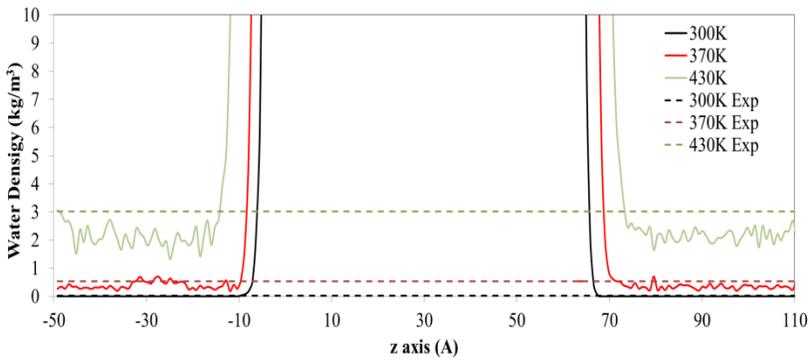


Figure 5 Comparison of saturated vapor water density calculated from molecular dynamics with experimental results.

Figure 3 shows the snapshot of water molecules equilibrated in air. It is very obvious there are fewer water molecules at the top and bottom of the column comparing to the center region of the column. Water density along the z axis is calculated based on the molecular dynamics results, and compared with the experimental results [3]. The comparison is shown in Figure 4 and 5. The water density calculated from molecular dynamics matches well with the experimental results. Now, it is very easy for students to understand the density difference between liquid and vapor, since in Figure 3 there are fewer water molecules per unit volume in the vapor region than in the liquid region.

Since this program is time consuming to learn, students do not learn how to use the program. The graphic outputs from the program can help them to better understand certain thermodynamics concepts from a microscopic view.

## CONCLUSIONS

This paper presented the use of three software packages in thermal-fluid science courses for mechanical engineering technology students. The software packages discussed in this paper are Automation Studio for fluid power, EES for thermodynamics and energy conservation systems, and molecular dynamics software for thermodynamics. Students learned to use Automation Studio and EES. Students do not learn to use molecular dynamics. The graphic outputs from this program help them to better understand certain thermodynamics concepts from a microscopic view. Students have positive feedback about the application of these three software in thermal-fluid science courses. A formal assessment of the effect of these three software will be performed in the future.

## REFERENCES

- [1] Esposito, A., 2009, "Fluid Power with Applications", 7th Edition, Prentice Hall.

[2] Plimpton, S., 1995, "Fast parallel algorithms for short-range molecular dynamics", *Journal of Computational Physics*, 117, (1): pp. 1-19.

[3] Cengel, 2008, "Introduction to thermodynamics and heat transfer", 2nd edition, McGraw-Hill