A new motivation and perspective on teaching simulation and design: The development of a dynamic process model in conjunction with an operator training simulator (OTS)

Introduction

During the past five years, the author was involved, as part of a team of researchers and developers, in building an **O**perator **T**raining **S**imulator (OTS) for an Integrated Gasification Combined Cycle (IGCC) power plant. In a companion project, a 3-D fully **I**mmersive **T**raining **S**ystem (ITS) was developed for the same IGCC power plant OTS. During this process, the educational potential of both the OTS and ITS became evident and provides the motivation for this paper.

Traditional process/plant design courses tend to focus on the formulation of steady-state models in which material and energy balances are obtained and unit operations are simulated. The resulting knowledge allows equipment to be sized, operating costs to be evaluated, and overall plant economics to be estimated. Such information also provides the basis for producing a preliminary process flow diagram (PFD). The operation of the process at the design condition provides a single operating point, and, while off-design conditions are sometimes considered, they are often not taken into account in the preliminary design.

In practice, the actual operating point of the process will rarely be at the design conditions. Moreover, the process will have to be started up and shut down many times during its life. Plant operations are, in principle, addressed in the traditional process control course(s) in the undergraduate curriculum. However, the operability of complete processes is usually outside the scope of these courses.

An observation from teaching process design over a period of approximately 25 years is that students have become increasing adept at using computer software and performing increasingly complex simulations using simulator software. Parametric optimization and extensive heat integration are examples of improvements that can be and that are now easily simulated but would have been nearly impossible or prohibitively time consuming only 25 years ago. This improvement in software acuity seems to come at the price of practical knowledge and appreciation of the basic chemical and physical phenomena occurring in process equipment; put another way, students are losing the ability to interpret the results that the simulator program "spits out."

In this paper, the author's experience in teaching a process simulation course using both steady-state and dynamic simulator software will be discussed. The motivation for teaching this course was to introduce students to some of the practical aspects of plant operation, to familiarize students with operator training simulators, and to simulate and operate a simple chemical process using a dynamic simulator that allows for the start-up and shut-down of the process being emulated.

Finally, the author will discuss some recent work in developing the 3-D immersive training system that allows students to experience a complete chemical plant in a virtual environment.

The 3-D-ITS is linked to the OTS and allows students or other operators to navigate through the virtual plant, to operate equipment, to make process changes, to observe process trends, to "see into" operating equipment, and to experience emergency situations. The potential for using such systems in chemical engineering education will be discussed.

Structure of the Process Simulation Course

The process simulation course was taught as a technical elective to 10 students (5 undergraduates and 5 graduates) in the Spring semester of 2012. The outline of the course is shown in Table 1.

Table1: Course Outline for Chemical Process Simulation Course

Week	Topics	Problem Set
1	Course introduction Introduction to steady-state simulators Structure of software interface Setting up a simulation	
2	Specifying conditions and thermodynamics Regressing thermodynamic data Solution methods Specifying equipment parameters Equipment sizing (and costing)	1
3	Parameter estimation Sensitivity and optimization studies Process case study	2
4	Introduction to dynamic simulators Structure of software interface Solution methods (pressure-flow vs. equation oriented)	3
5	Initial conditions, trending, sources and sinks	4
6	Critical dynamic data Transient analysis	5
7	Example 1 - dynamic simulation	6
8	Example 2 - dynamic simulation	7
9	Example 3 - dynamic simulation	8
10	Introduction to operator training simulators, Human machine interface, alarms and controls	
11	Start-up and shut-down procedures Immersive training simulators Class project on IGCC OTS (IGCC overview)	
12-15	Work on class project	

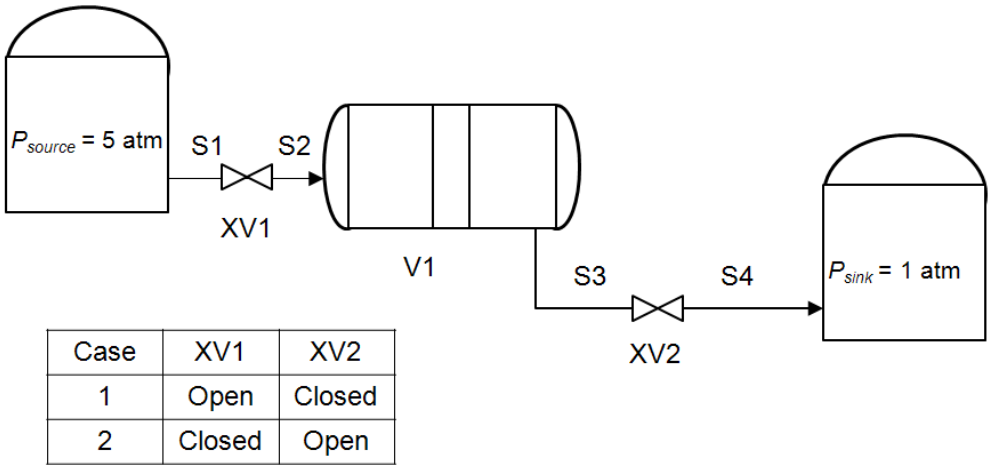
As can be seen from Table 1, the first three weeks of the course comprised a review of some of the more advanced features of the steady-state simulator that is used in the undergraduate curriculum (CHEMCAD™ by Chemstations). The remainder of the course focused on dynamic simulation (the software platform used was DYNSIM™ by Invensys Operations Management).

When teaching a course involving the use of sophisticated software, it becomes a balancing act between teaching how to use the software and the basic pedagogy of the underlying course content, which in this case was dynamic simulation and process plant operations. For this course, the approach taken was to introduce a series of process problems, simulate them, and then discuss some of the practical issues of implementing these systems in the "real world" by conducting dynamic "experiments" using the simulator. A simple example of filling a tank is used to illustrate this approach.

Example 1: Tank Filling

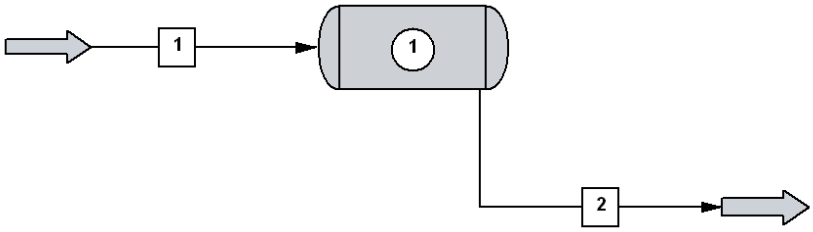
The diagram for the dynamic simulation is given in Figure 1(a), which illustrates the set up for the problem and defines two cases that were considered. The flow diagram shows a pressure source containing a liquid at 5 atm connected through a valve, XV1, to a process vessel, V1, with the bottom of the vessel connected to a pressure sink at 1 atm via a valve, XV2. It should be noted that the corresponding steady-state simulation consists of a feed connected to the vessel with a product line leaving the vessel and is shown in Figure 1(b). The valves in Figure 1(a) are required in the dynamic simulation, because the source, sink, and vessel are pressure nodes that must be separated by flow resistances – valves. The valves could be replaced by pipes. The two cases shown simply demonstrate tank filling (Case 1) and subsequent tank emptying (Case 2).

The transient history for Cases 1 and 2 are illustrated in Figure 2. The top diagram is for tank filling and the bottom diagram is for tank emptying. It should be pointed out that there was a residual level of water in the tank before the cases were run. The interesting point is that the tank neither overflows (maximum height = 1 m) nor does it drain completely for Cases 1 and 2, respectively. This result was surprising to the students and was counterintuitive to what they expected. The discussion in class centered on the final conditions, at which flow had stopped. The only logical explanation was that at this point, the pressure in the process vessel must be equal to the source (for filling) or the sink (for draining). This was checked by repeating the simulation and plotting the pressure, in addition to the level, as a function of time, as shown in Figure 3. As expected, the pressures do asymptotically approach those of the source and sink (with allowance for the difference in heights of the equipment). These results lead to a discussion of why the pressure changes in the tank and how to alleviate this issue. What is happening is that as the tank fills with liquid, the vapor space above the liquid in the tank is compressed and the pressure increases, with the opposite effect happening during tank emptying. The obvious solution is to provide a vent at the top of the tank that allows the vessel contents to "breathe." In the case of a simple water tank this would simply be an open pipe connected to the atmosphere. If the liquid had appreciable vapor pressure (say for a hydrocarbon) then the use of a nitrogen blanket would be appropriate.



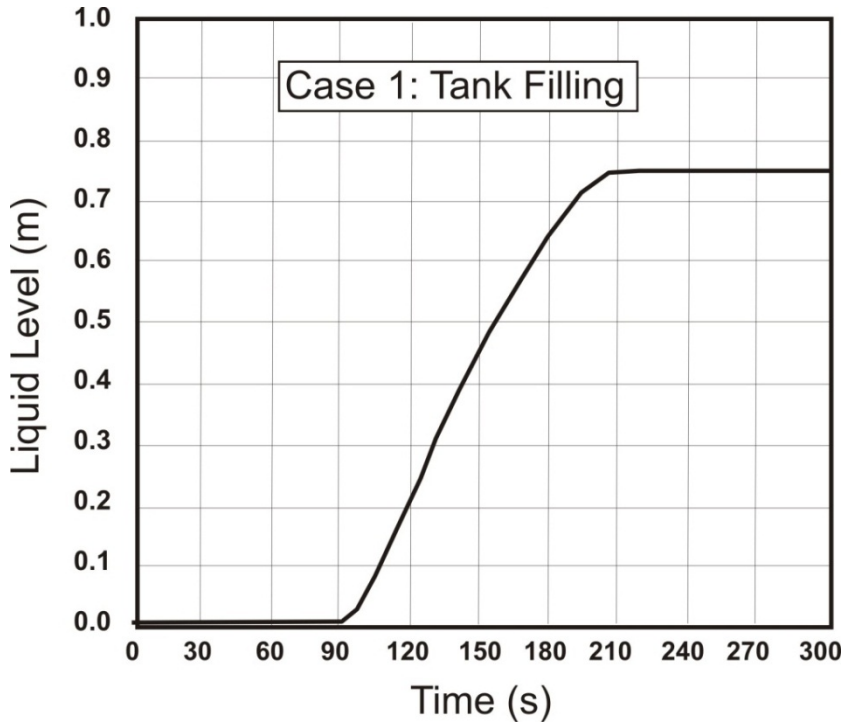
Case	XV1	XV2
1	Open	Closed
2	Closed	Open

(a)

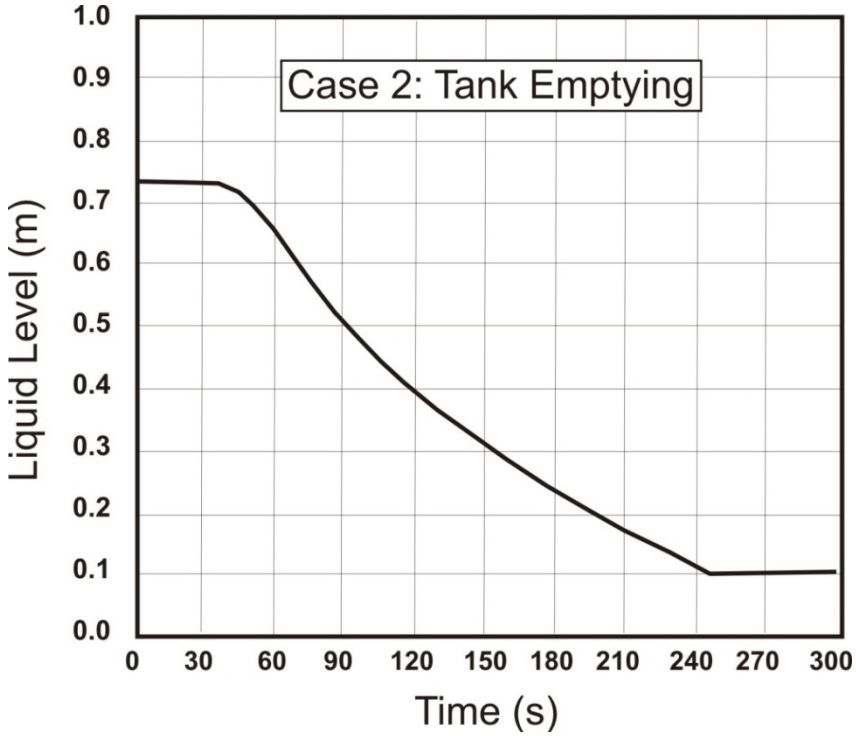


(b)

Figure 1: Example of liquid filling a tank (a) dynamic flowsheet (b) steady-state flowsheet

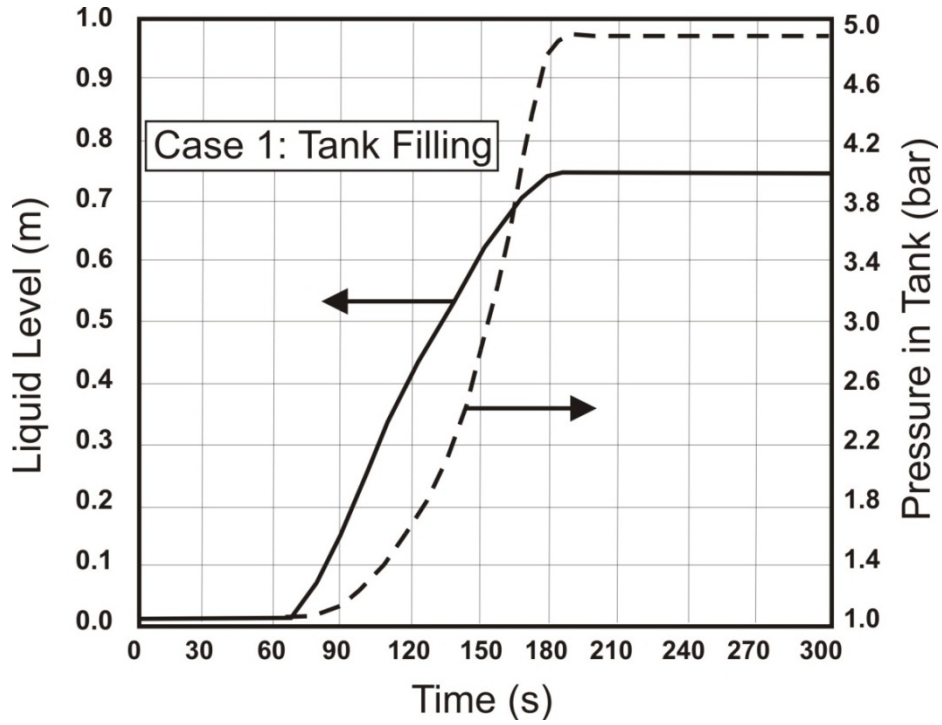


(a)

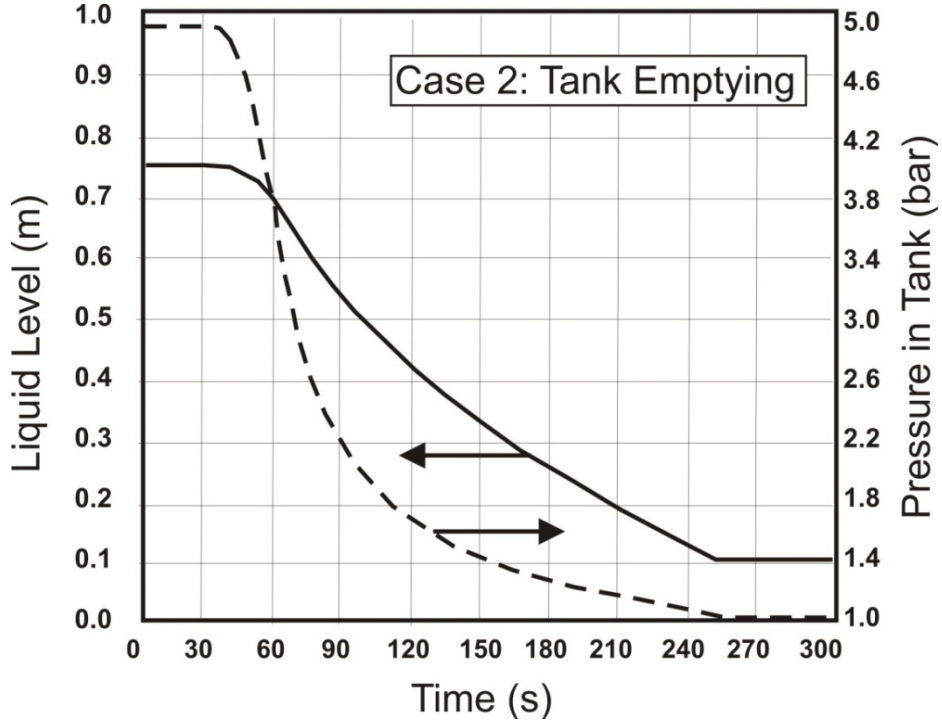


(b)

Figure 2: Transient response for Cases 1 and 2 (a) tank filling, (b) tank emptying



(a)



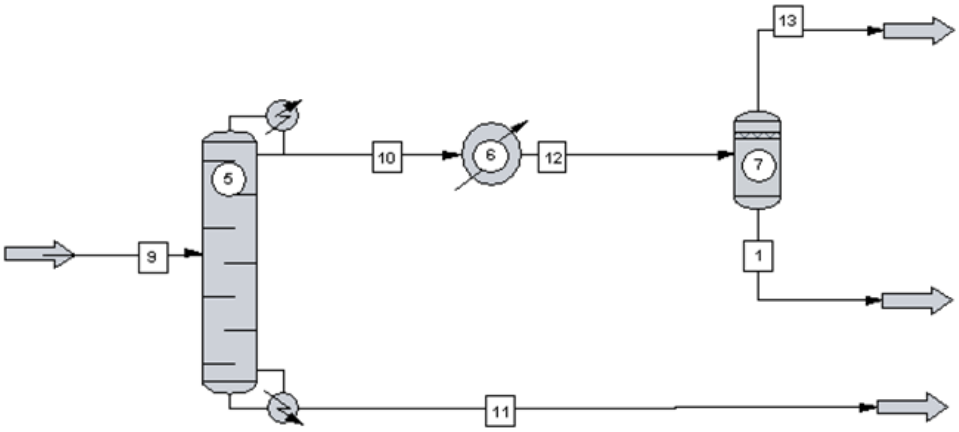
(b)

Figure 3: Transient responses for Cases 1 and 2 showing pressure and liquid level histories (a) tank filling, and (b) tank emptying

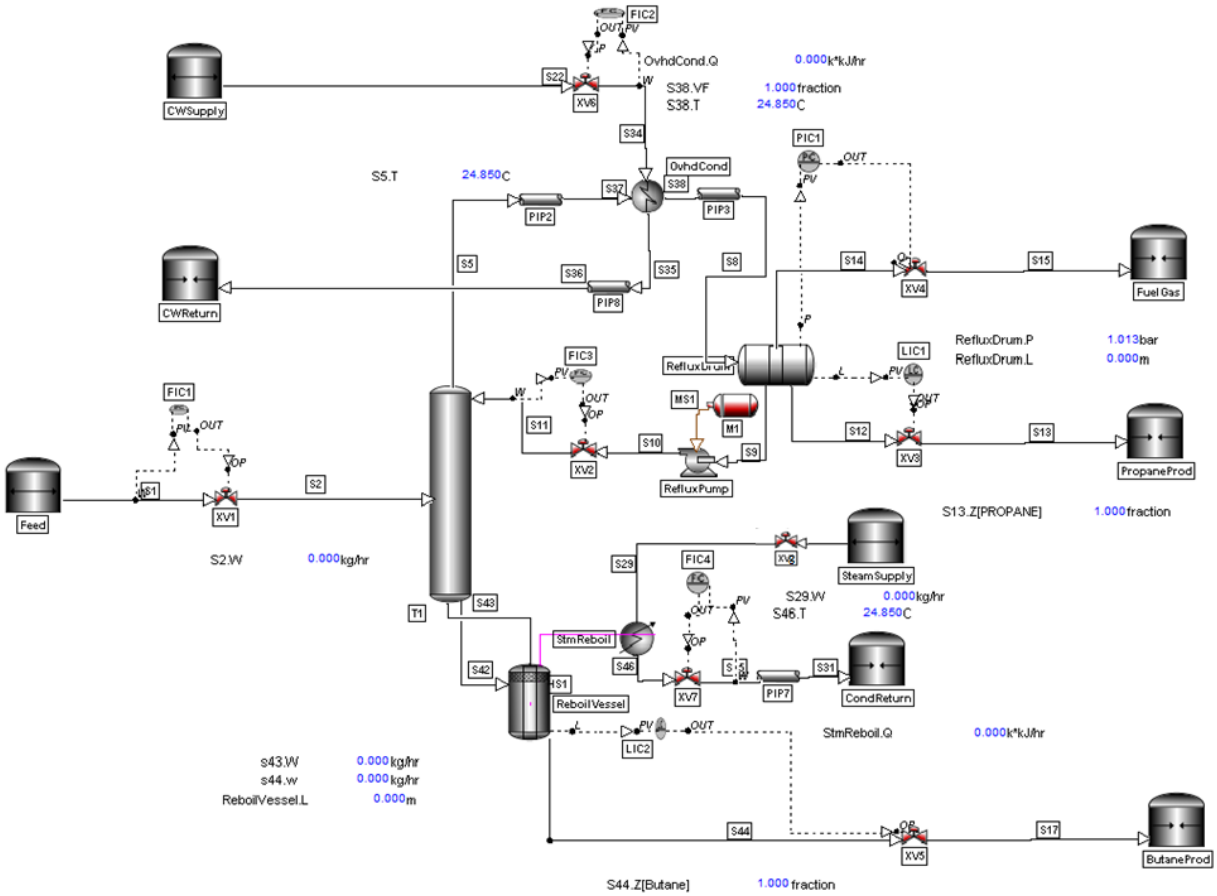
The important “takeaways” from this example are that it is important to understand exactly what is happening in the physical world in order to understand the response of the system. Second, what appears to be a trivial example for steady-state analysis may be more complex in the dynamic mode. Finally, additional controls and equipment may be needed in the real world to have the equipment behave realistically.

Development of a simple process through structured examples

The middle section of this course, Weeks 4-9 in Table 1, was organized around developing a dynamic simulation of a simple process that would cover many of the basic operations and process control strategies needed for the final project. The process chosen was a depropanizer that is a distillation tower that separates propane from heavier hydrocarbons. For the example chosen here, a feed of light hydrocarbons ranging from C_5 to C_1 and some hydrogen was used. This process is essentially a fairly simple distillation, in which propane is removed from heavier hydrocarbons, but requires a vent from the overhead reflux drum to control the pressure of the column. The column was first simulated in the steady-state simulator as shown in Figure 4(a). The vent of light gases from the overhead reflux drum is simulated by using a partial condenser and then taking the vapor product and condensing it in another exchanger prior to separating the liquid overhead product from the vent gas. This arrangement of equipment is clearly not what exists in the real plant, since no additional exchanger is present, but rather all the condensing and cooling is achieved in the single overhead condenser. Nevertheless, the steady-state simulation does provide the approximate energy and material balances and equipment parameters for the design condition. To compare this result with the dynamic model, Figure 4(b) shows the flowsheet for the same depropanizer system using the dynamic simulator. It is clear that the dynamic simulation results in a much “richer” description of the process and requires significantly more practical knowledge and understanding in order for it to run successfully. A comparison of the type of information needed for each type of simulation for the depropanizer example is given in Table 2.



(a)



(b)

Figure 4: Flowsheets for the depropanizer example problem (a) steady state simulation, (b) dynamic simulation

Table 2: Comparison of information needed to simulate the depropanizer example successfully for steady-state and dynamic simulations

Steady State	**Dynamic**
Towers have integral condenser and reboiler.	Each piece of equipment is simulated separately.
Give top and bottom specifications – reboiler and condenser duties adjusted to meet specifications. Equipment size not required but can be calculated.	Equipment specified in terms of its physical dimensions and attributes. Equipment size is required data.
Equipment elevations not needed	Equipment elevation is required and both gravity flow and pressure driven flow may be simulated.
Reflux drum and reflux pump are not specified, and venting of non-condensable from reflux drum is difficult to do.	Vents and vapor blanketing are easy to accomplish in reflux drums and must be included with appropriate controls.
Flows and pressures specified – pressure does not affect flow.	Pressure-flow network is specified. Each piece of equipment is a pressure node and must be separated by flow resistances (valves or pipes).
No process control required	Process control must be included to obtain stable operation
Uses/generates data from/to **PFD**	Data on the **P&ID** are needed

When developing the dynamic depropanizer case study in class, several process concepts were reviewed. For example, in order for the reflux pump to work properly, the pressure head developed across the pump must be specified correctly, which leads to a discussion of the relative elevations of the reflux drum, pump, and reflux return to the tower and also the pressure difference between the reflux drum and the tower. A review of pump and system curves was given in order to reinforce these concepts. The dynamic simulator can also be used to calculate the NPSH available and check for cavitation; although, this was not covered in the project.

Another example that was discussed was the need for the vapor line from the reflux drum that allowed the hydrogen and lighter hydrocarbons to vent and which was used to maintain pressure control in the overhead system. It was noted that during start up, it took a considerable amount of

time to get the reflux drum and the overhead system to pressure using the configuration shown in Figure 5(b). This was because when the overhead vapor flow is low, it was difficult to regulate the amount of condensation in the overhead condenser and the reflux drum pressure would swing widely. This problem was discussed and possibly remedies such as having a hot gas bypass around the condenser or a natural gas blanket on the reflux drum were suggested.

Written Procedures for the Start-up of the Process

During weeks 10 and 11 (Table 1), students spent a day at the Advanced Virtual Energy Simulation and Training (AVESTAR) Center at our University. The centerpiece of the center is a fully functional, high-fidelity operator training simulator (OTS) for an IGCC power plant. The purpose of this experience was to expose students to all the features of an OTS and to have them start up a portion of the process. One of the major objectives of this exercise was for them to follow a comprehensive set of written procedures that are used to guide the operator and/or engineer to start up the plant.

The process unit chosen was the sulfur recovery unit (SRU) or Claus Unit that converts H_2S to elemental sulfur. This unit was chosen because it is a relatively straightforward process (needing ~30 steps) and it can be started up in a 4-6 h period. The two groups of students spent a day at the AVESTAR Center following the start-up procedure for this process unit. During that period, the students were exposed to digital logic such as permissives and regulated procedures for complicated equipment such as the Claus furnace. A sample of the written procedures for this part of the IGCC is repeated in Table 3. All students participated in this activity and the four groups were all able to start up the unit successfully, with about the same level of guidance from the instructor. The “takeaways” for this experience were (1) adhere strictly to the procedures (2) do not skip steps (3) wait until the intended action is achieved before starting the next step, and (4) be patient and do not hurry steps.

After the experience at the AVESTAR Center, students were then asked to write up start-up procedures for the depropanizer that was developed in class. The results for this exercise were varied, and despite the experience gained on the simulator, there were many mistakes in writing up the procedures. Some of the common mistakes are shown in Table 4. A thorough review of the mistakes made in the start-up procedures was given. Emphasis was given to the consequences of making errors in the procedure. Therefore, not only would the process not start up causing costly overruns during commissioning the plant, but equipment could also be damaged and the plant could become unsafe.

Table 3: A portion of the start-up procedures for Unit 1300-SRU, the Claus unit

SRU S/U Sequence - All steps mentioned in this sequence pertain to Area 1300				
Step	**Action**	**P&ID**	**DCS Screen**	**Notes**
572.	Ensure gas flow is set to go to the incinerator and not to the hydrogenation unit. Open RF010 to the Incinerator and block the flow to the TGTU by closing the RF011.	1300-SRU-002		A1305_Third_Sulf_Cond FS
573.	Make sure all the Permissives are met to start the R1300	1300-SRU-001	Claus Plant S2 Converter/Condenser	
574.	Press the R1300 RESET Button and then initiate the Claus Furnace Purge and Heat up by pressing the R1300 STARTUP Button	1300-SRU-001	Claus Furnace and Waste Heat Boiler	
575.	Wait till the Claus Furnace Temperature increased up to 2500°F	1300-SRU-001	Claus Furnace and Waste Heat Boiler	
576.	Place WHB Steam drum overpressure controller PC001 in AUTO with a SP of 570 psig	1300-SRU-001	Claus Furnace and Waste Heat Boiler	
577.	Once the Waste Heat Boiler Pressure reaches 570 psig. Open the MV015 bleed valve RF015 to balance the pressures. After 30 seconds, the MV015 valve should open to send the IP steam to the IP Steam Header	1300-SRU-001	Claus Furnace and Waste Heat Boiler	A1302_Furnace_WHB FS
578.	Wait till the IP steam flow increases up to approx 10,000 lb/hr. If needed increase the FC003 (Air flow) SP to generate more IP steam.	1300-SRU-001	Claus Furnace and Waste Heat Boiler	
579.	Place temperature controller for the Catalytic convertor preheaters TC004 and TC005 in AUTO with SP of 467°F and 420°F respectively.	1300-SRU-002	Claus Plant S2 Converter/Condenser	
580.	Place steam side controller for the Catalytic convertor preheaters LC006 and LC008 in AUTO with SP of 46% for both controllers.	1300-SRU-002	Claus Plant S2 Converter/Condenser	
581.	Set both PC002 and PC003 in AUTO with a SP of 60 psig to build the pressure in the First and Second Sulfur Condenser	1300-SRU-002	Claus Plant S2 Converter/Condenser	

Table 4: Common mistakes in writing start-up procedures for the depropanizer process

Type of Error	Examples and Remedies
Vague instructions	**Poor** - "increase the flow a **bit** so that you get a **level** in the reflux drum" **Better** – "set valve XV1 to manual and open to 5% then wait until liquid level in drum V-1 reaches 0.6m…"
Using Unmeasurable Variables	**Poor** – "adjust cooling water flow through XV2 so that **vapor fraction** at outlet of overhead condenser is 0.07" **Better** – "adjust cooling water flow through XV2 until temperature at outlet of overhead condenser is 52°C"
Skipping Steps	

Class Project

During the last four weeks of the class, the students were divided into two groups (one group comprised of undergraduates and the other made up of graduate students) and each group was asked to develop a dynamic model for a different chemical process. The problem statement for the project and assignment of grades are given in Table 5.

The first task was to develop a steady-state model for the chemical process of choice and this was given as a homework assignment early in the semester. Feedback on the assignment and appropriate revisions were made to ensure that both groups had a viable steady-state simulation for the project. Tasks 1(c-e) were also covered in the course, either as problem assignments or as in class exercises. Therefore, algorithms for determining equipment sizes, estimating the metal mass of equipment (important in determining the time to reach a steady-state temperature), control valve sizing, and basic inventory control schemes had all been covered prior to the project assignment. The two major tasks that remained were to develop the dynamic model and to write start-up procedures to take the unit from a cold condition to steady state and to check that the steady state condition against the one derived in Part 1(a) of the project.

The high weighting for writing the start-up procedures was not arbitrary but carefully considered to focus students to analyze and synthesize their design in terms of the physical processes involved in the simulation. The following caveat was added to the problem statement to emphasize the need for clear concise instructions and to focus the groups on providing unambiguous and clear instructions:

"The instructor (the author) will sit down with your model and your set of instructions to start the plant up. You will not be around to advise or to offer help. Your grade will depend on how many times the instructor has to deviate from your instructions in order to start the process up"

Table 5: Project assignment and grade breakdown

Project Topic	% of Project Grade	Comments
1. Dynamic model development a. Establish steady state design case in Chemcad	10	Done in PS # 3
b. Establish and demonstrate dynamic model has same steady state conditions as part (a)	30	Need to show that the steady state case from Dynsim is equivalent to the Chemcad simulation
c. Correct equipment sizing	4	Use approximate techniques to estimate surface area and metal mass
d. Safety Equipment included	3	Include safety relief valves and anti-surge control. Add pump cavitation protection, etc.
e. Correct valve sizing included	3	Size all control valves so that steady state gives 60-70% open
2. Start-up Procedure	50	Provide a detailed, unambiguous procedure to start-up the process from an initial condition of all equipment filled with natural gas – natural gas pressure available at 25 bar.
Total	100	

Results from the Class Project

Results from both groups were similar. Both groups provided a complete dynamic model that gave steady-state results similar to the steady-state simulations. Equipment sizing and safety features were modeled reasonably well with one group implementing a spill-back surge control loop for a compressor and both groups implementing safety relief valves where necessary. Both groups also implemented digital permissive controls on pump starts that prevented the pump motor from starting unless a minimum liquid level was present in the appropriate suction vessel.

One group provided extensive start-up procedures (73 steps) while the other wrote 36 steps. An excerpt for the group of undergraduates is given in Table 6. Despite the repeated exposure to and critiquing of these procedures, the author had difficulty in successfully starting up both processes. A partial critique of one of the reports is given in Table 7.

Table 6: Start-up procedures for Project A - DME process

Operating Procedure for the Start-Up of the DME Production Facility

Before starting the simulation (but after loading it up), turn controllers (FIC 201-207, LIC 201-205, PIC 203, & TIC 202) to manual except pressure controllers (PIC 201-202 & 204-205) and temperature controllers (TIC 201, 202b 203).

(At this point, you can start the simulation.)

1) Open FIC 202, 204, 205, and 207 to 1% open to begin heating the metal mass of heat exchangers, E-204, E-205, E-206, & E-207, respectively.
2) Open XV7, XV2, to 100% open
3) Open FIC201 to 5% open.
4) Open XV12 and XV18to 100%, and set PIC203 to 100% manual output,
5) Set LIC 201 to auto to begin filling V-201
6) Once level in V-201 is 0.5 m, start P201A (Note: If level in V-201 is below 0.5 m, the pump will not start.)
7) Once pressure in R201 reaches 1470 kPa, set PIC203 to auto
8) Once level in E204a reaches 0.5 m, open FIC204 to 5% to begin pressurizing T201 (Note: Final pressure in T201 system should level out to 1030 kPa. However, at start-up the pressure may rise above this pressure.)
9) Once temperature in R201 reaches 320°C, open FIC201 to 10% open
10) Monitor the flows inside T201, and notice that once liquid is on all of the trays, the temperature coming out of the top of T201 should begin to rise.

A total of 73 steps

Table 7: Critique of Project A

Positives
• A comprehensive set of start-up procedures was provided. • Improvement – It would have been helpful to have added a modifier such as "increase FIC20Y until something happens, then increase……"
• The procedure for starting the recycle stream and for removing the hot oil utility and starting the reactor feed/effluent exchanger was very good
• Equipment sizing was done correctly
• The Dynsim flowsheet was neat and easy to follow and you used the same or close to the same labels as in the PFD.
• I probably could have started the unit up with some assistance from the group.
Negatives
• Descriptions about when to move to the next step should have been more explicit, as many of the instructions were of the form o *i* increase valve FIC20Y to 30% o *i*+1 increase valve FIC20Z to 3% o *i*+2 increase valve FIC20W to 7%, and so on Instructions should have been of the form "do something until something happens and then …."
• I tried to start the process about 10 times and never got past Step 27. Tower 1 gave all sorts of problems – wild pressure swings with corresponding (maybe unrelated) vapor rates in the reboiler.
• The reaction of methanol in the reactor was essentially complete (i.e., 100% conversion) for most of the run – this means that there is virtually no methanol to recycle from the first column – **This is a reactor sizing error**
• The flows out of the first tower reflux drum going to Flare 2 become liquid when the drum overfills – thus dumping liquid out the vapor line!
• The overhead reflux pump for T-201 has intermittent vapor in the line (NPSH issue) - need to adjust the heights of the drum and pump and change the CV on the suction valves to eliminate this problem.

Overall Results and Impressions about the Project (Students)

Despite the difficulty in starting up both the processes, the level of detail and enthusiasm from both groups was impressive. Groups realized the need to assess their instructions in a blind test and split each group in two with one portion of the group starting up the process and providing feedback to the other half of the group. In retrospect, it would have been better to have the each group try to start up the other group's process using their set of instructions and providing feedback prior to submitting the report to the instructor. This would have eliminated many of the problems found by the instructor.

Feedback from the students (both through informal discussions and the formal course evaluation process) was very positive. Some comments were; "Project was a lot of work," "I learned a lot from this course," "time really flew by in this class," "this course should be mandatory for all ChE students."

Instructor's Impression about the Project and Course

From the author's perspective, the course was a very good experience and one that I plan to repeat next year with an expanded but limited enrollment. There are some essential skills that need to be mastered prior to undertaking a course such as this one. First, a mastery or familiarity with the software is essential. The dynamic simulator (Dynsim) used in this course is relatively straightforward to learn and Invensys's university helpline was very accommodating in answering questions and troubleshooting system problems. As projects are developed during class, with students working on their own or with a partner, input errors are commonplace, and the instructor must feel comfortable troubleshooting these "on-the-fly." The number of students in the course must also be manageable, a maximum of 20, without the help of a teaching assistant, is recommended. Exposure to an OTS is a benefit but certainly not essential – the depropanizer example that was developed during the class is certainly complex enough to convey all the necessary concepts taught in this course and makes a relatively simple practice process to develop start-up procedures and test basic control strategies, etc. The depropanizer files and a comprehensive start-up procedure will be developed by the instructor for the next time that this course is taught and will be made available to other ChE faculty interested in teaching a similar course.

In terms of student learning, this course reinforces several of Bloom's (cognitive domain) higher learning objectives, namely: analysis, synthesis, and evaluation. In developing the course project, the need for the student to analyze the results from the simulation in the context of how the operation of a given process unit might affect some other unit was emphasized. Similarly as problems were encountered in the project, students were asked to troubleshoot these issues through analysis of the whole flowsheet and with this information synthesize potential remedies for the problems encountered such as changing the control structure, retuning controllers, and changing the topology of the process. Finally, in writing the start-up procedures students learned to test a part of the process, synthesize the response, make changes to the process if needed, and to evaluate the amended procedure in light of the changes made.

3D-ITS

Improvements in computer animation can be attributed to the increasingly sophisticated video gaming industry and the appeal of computer generated movies such as Shrek, Avatar, etc. Indeed, much of the advanced medical imaging techniques in use today are derivative of these industries. In the same way, the ability to produce photo-realistic images of chemical plants and to recreate a part of or a whole chemical process in a virtual environment is now a reality. Moreover, using a game-pad, an avatar of a plant operator can be manipulated to walk through the virtual plant and perform a variety of actions, such as turn equipment on and off, observe active control elements such as gauges and motor switches, pull-up trends of key process variables (liquid levels, pressures, temperatures, and compositions), and troubleshoot malfunctions in the virtual plant. In addition, unlike in a real plant, the operator may make use of the virtual environment and peel back the walls of equipment and see what is happening in side. Because the ITS is linked to the OTS, actions in either system can be seen in the other. Therefore, if an operator opens a valve in the ITS, the change in position of that valve is shown in the OTS. Alternatively, if the level in a suction drum that feeds a pump drops too low, then the operator in the field can go to that vessel and actually hear the pump cavitating. Similarly, leaks and spills can be simulated in the ITS and students experience the consequences of emergency response techniques to mitigate these upsets without the danger involved in performing similar drills in the real plant.

As the integration of 3D-immersive training systems becomes more popular, the integration of these systems into the chemical engineering curriculum seems a natural move. Some of the features of the ITS system available at our university are illustrated in Figure 5 and illustrate the richness of the virtual environment. Two examples of how student activity might be affected by ITS technology are:

- In laboratory sessions, students might perform virtual experiments on a distillation tower that processed a toxic or explosive chemical (impossible to do in current day unit operations laboratories). The virtual equipment might be of commercial scale, comprising say of a tower 5 m in diameter containing 120 trays along with a thermosiphon reboiler, a partial condenser, reflux pumps, overhead drums, etc. A team of students might be set a task of evaluating the separation efficiency of the tower by having an avatar climb to various locations and pulling virtual gas and liquid samples for analysis. With this data, tray efficiencies could be calculated and compared with typical values for similar towers/systems.

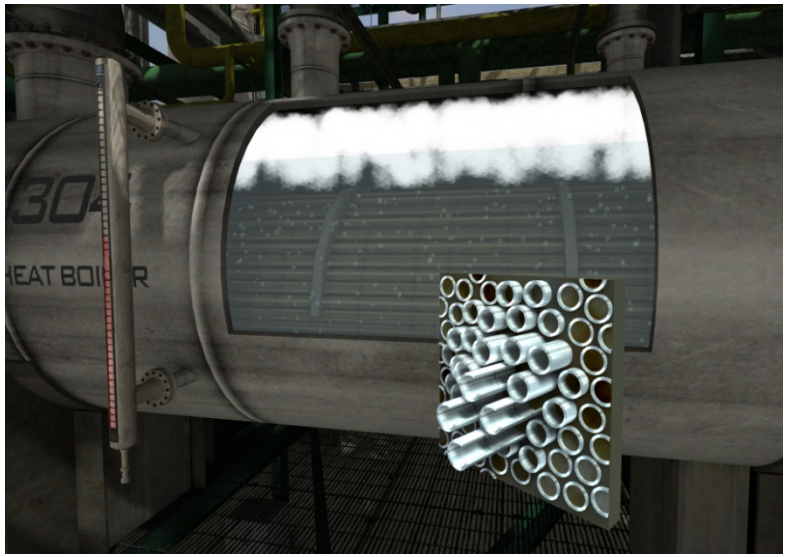
- In the classroom, an instructor might demonstrate the operation of a reactor, pump, or tower by removing the outer wall of the virtual representation of the equipment and showing the internal structure of the equipment. Flow patterns, temperature and component profiles, and other pertinent information could be displayed with such information obtained through rigorous CFD simulations and “superimposed” on the equipment. Alternatively, simple experiments could be simulated in 3D and used to demonstrate basic chemical engineering principles without the need for setting up real equipment and/or taking the students to a laboratory. Indeed, any situation that can be imagined can be simulated, represented, and demonstrated in the 3D environment.

Students will be exposed to the ITS for the first time during the process design course in 2013 and results from that interaction will be discussed in a future presentation. Work has also started on making 3D modules available to universities.

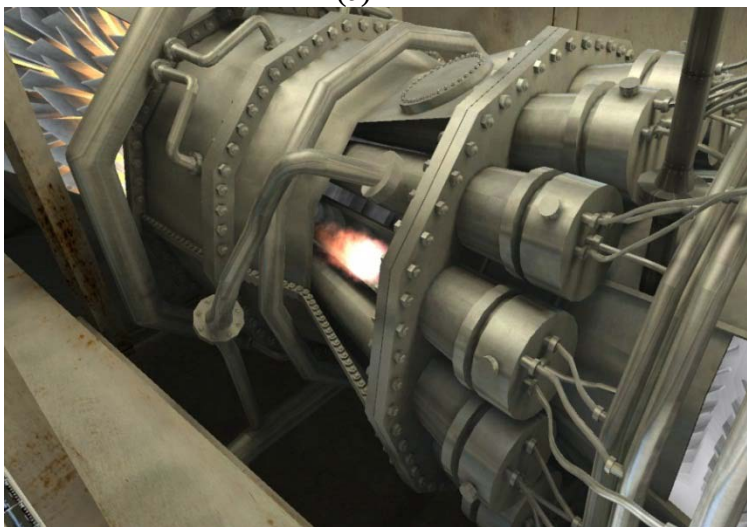
Conclusions

Process simulation techniques for both steady- state and dynamic simulators were covered in a new, elective course. A case-study approach to learning dynamic simulation was adopted. Class exercises and problem sets were assigned to develop skills needed to simulate a simple chemical process. Exposure to a fully functioning operator training simulator allowed students hands-on experience in starting up a process unit that was part of a very complex power generating system. The final project in the class involved the development of a dynamic simulator for a chemical process and the subsequent development of a set of operating procedures for starting up the process. Future work in this area will focus on integrating a 3D immersive training system (a virtual process plant simulation) into different areas of the chemical engineering curriculum.

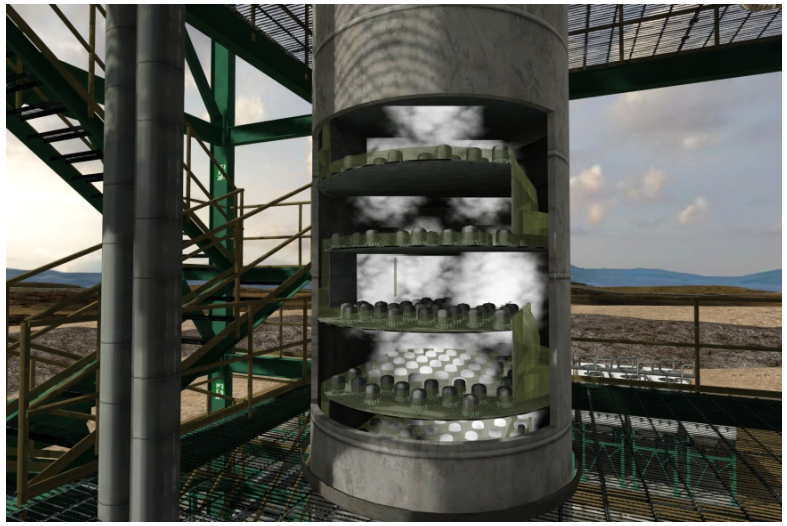
(a)



(b)



(b)



(d)

Figure 5: Examples of 3D-immersive training system, (a) process fire, (b) details of tube bank in a reboiler, (c) details of an igniter in a gas turbine, and (d) a view of the internals of a distillation column. (Courtesy of Invensys Operations Management)