Session 1526

Experiments in Membrane Separation Processes Delivered Through the Internet

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Abstract

This paper describes the development of Internet-based unit operations laboratories illustrating membrane processes: dialysis and nitrogen production from air. Potential software and hardware approaches to remote experimentation are summarized. The implementation of each experiment in a Windows 2000 environment is presented – detailed equipment lists and costs are provided.

Several options for providing video and audio signals were evaluated including: (1) RealNetworks streaming media, (2) NetMeeting, (3) Polycom ViewStation FX, and (4) Polycom ViaVideo Desktop System. Each offers different combinations of video quality, latency, and cost. The impact of the video/audio signal on the educational effectiveness of the experiment is discussed.

Preliminary evaluations of the learning effectiveness of these experiments are presented. Learning, attitudes, and collaboration of students who completed the dialysis experiment were assessed through focus groups. The results will be used to guide future evaluations of the experiments. Assessment focused on the following specific issues: (1) student motivation (student interest in achieving learning objectives, enjoyment of the laboratory exercise, and personal interest in the content), (2) level of student comfort with performing an experiment through the Internet, (3) degree to which students perceive the experiment as authentic, and (4) the extent of collaboration between students and between students and the instructors.

Motivation

Internet-delivered Unit Operations Laboratory experiments (real-experiments run in real-time) could have a profound effect on education. Such experiments could provide access to modern, relevant experiments in Chemical Engineering areas that would not be available otherwise due to lack of funding, time, or expertise. Moreover, departments would not have to maintain as many experiments which would free funding for developing new experiments or updating existing ones.

Internet delivery could increase access to modern experiments while simultaneously saving money. To illustrate the potential, consider the University of Toledo's Chemical Engineering

Unit Operations Laboratories: Lab I and Lab II. Lab II is run one semester a year while Lab I is run two semesters to accommodate the schedule of co-op students; the equipment is idle otherwise. During the active semester, students use the equipment only two or three afternoons a week for three hours. This equipment must be maintained and replaced on a regular basis despite its low utilization. We recently spent $250,000 in renovations for six experiments: an average cost of ~$40,000/experiment. If each of the nine Chemical Engineering departments in Ohio were to perform similar renovations the total cost would be $2.25 million.

Now consider what one could do if each school developed two new experiments at $70,000 each; the extra $30,000 would be used to make the experiment Internet accessible and purchase higher quality equipment. The total expenditure would be $1.26 million and students would have access to 18 new experiments. The cost of renovation is cut by $1 million (~50%) and students have access to 12 more new experiments (~ 3 times more!). Use of the equipment would require efficient scheduling but with the equipment available 24 hours a day significant flexibility exists. Such savings could be realized across the curriculum at all educational levels.

To realize the benefits of Internet delivery, however, the educational experience must be equivalent to or better than that of a hands-on experiment. The project described here seeks to determine if this is true or false.

Experimentation through the Web

Most of the work to develop Internet-based laboratories has utilized National Instruments' LabVIEW™ software. National Instruments maintains links to academic institutions that have utilized LabVIEW™ in the development of such laboratories [1].

LabVIEW™ in conjunction with the Internet Developers Toolkit for G provides a comprehensive software environment for developing Internet-delivered laboratories. LabVIEW™ provides numerous procedures for data acquisition and control over a network. The procedures differ in what software is required by the client – the computer that is accessing the server or experimental data acquisition and control computer.

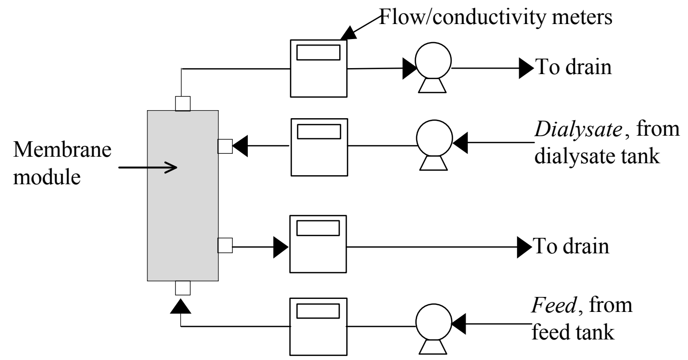
LabVIEW™ uses a virtual instrument (VI) paradigm for software development. A VI typically consists of software that accesses data acquisition and control hardware attached to the computer and displays the results in a graphical user interface (referred to as the front panel). If the client and server run LabVIEW™ one can access the VIs on the server from a VI on the client using remote VI calls or through the VI server. The disadvantage of this approach is the need to install LabVIEW™ or the LabVIEW™ run-time engine on the client.

Alternatively, one can access VIs on the server through a web browser. Using LabVIEW™'s web server, one can view static images of VI front panels. Periodic updating of the images allows one to view changes. VIs can be controlled by submitting forms to the web server. Form data can be passed to a data acquisition and control VI through the CGI interface and VI server. The disadvantage of using forms and static images is loss of near real-time interaction with the experiment. To provide increased interaction, web pages may contain embedded controls (using Java or ActiveX) that receive a continuous stream of data from VIs through the DataSocket server. These controls often require significant additional programming, beyond that to develop the data acquisition and control VI. One can avoid this additional effort by using the LabVIEW™ web browser plug-in. While this requires installation of the plug-in, it can be performed automatically when the web page loads. Our initial work has utilized this last approach to minimize the development effort required.

Dialysis Experiment

The dialysis experiment is illustrated in Figure 1. This process is used to partially replace kidney function in patients suffering from kidney disease and in the separation trains used to purify biotechnology products. The feed, containing a solute that one wishes to remove, is typically sent to the lumens of the fibers in the membrane modules. A second stream, the dialysate is introduced into the space outside the fibers. The solute is removed by diffusion from the feed to the dialysate. The feed and dialysate contact each other in a counter-current fashion to maximize mass transfer. Students are asked to measure mass transfer coefficients for a dialyzer as a function of feed and dialysate flow rates and to compare the experimental values to theoretical values for randomly and regularly packed fiber bundles.

Figure 1. Dialysis experiment schematic.



For the experiments, sodium chloride is removed from water using a Fresenius F80A module. Peristaltic tubing pumps control the lumen and shell inlet flows as well as the lumen outlet flow. Students are asked to keep the inlet and outlet flows equal. However, future experiments could study the effect of ultrafiltration (the difference between the lumen inlet and outlet flows, i.e., the flow rate from the lumen to the shell *across* the fiber wall) on mass transfer.

Figure 2. Photograph of dialysis experiment. The module is the white cylinder in the middle of the blue board. The blue cylindrical tank to the left contains the salt solution feed.

The lumen feed, the sodium chloride solution, is taken from a storage tank that must be refilled periodically. The shell feed is taken from a storage tank that refills automatically from the cold water line. The lumen and shell outlet streams are sent to a drain.

Flow rates are measured with flow meters while concentrations are measured with in-line conductivity meters. Table 1 contains a detailed list of the experimental equipment including data acquisition and control hardware. A photograph of the experiment is provided in Figure 2.

Table 1. List of experimental equipment and data acquisition and control hardware for the dialysis experiment. Total cost: ~$7500.

Quantity	Item	Manufacturer	Model #
3	Peristaltic Pump	Master Flex	77521-40
3	Pump Head	Master Flex	77200-62
4	Flow Meter	McMillan Company	S-111 S6
4	Conductivity Controller	Cole-Parmer	U-19300-10
4	Conductivity Cell (flow through)	Cole-Parmer	U-19500-30
1	Dialysis Module	Fresenius Medical Care NA	F80A
1	Multifunction I/O NI-DAQ	National Instruments	PCI-6023E
	Channels used:		
	4 analog inputs and 4 grounds for flow meters		
	4 analog inputs and 4 grounds for conductivity meters		
1	Analog Output NI-DAQ	National Instruments	PCI-6703
	Channels used:		
	3 voltage outputs and 3 grounds for pumps		
2	Shielded Connector Block	National Instruments	SCB-68
1	Shielded Cable	National Instruments	SH68-68-EP
1	Shielded Cable	National Instruments	SH68-68-D1
1	Computer	Virtual PCs	
	Pentium 4 1.8 GHz, 1GB DDR Ram, Windows 2000 OS, LabVIEW 6.1		
1	Video Capture Card	ViewCast Corporation	Osprey-220
1	Video Camera	JVC	GR-DVL9800

<u>*Gas Separation Experiment*</u>

The membrane gas separation process and equipment is shown schematically in Figure 3. This process is used commercially to produce enriched nitrogen and oxygen from air. The enriched nitrogen is used in blanketing and inerting applications while the enriched oxygen may be used for medical purposes.

In operation, compressed air is fed to the module along the path at the bottom of Figure 3. Most modules use hollow fiber membranes in a shell and tube configuration. By controlling the indicated solenoid valves, one can introduce the feed into either the fiber lumens (bottom port) or

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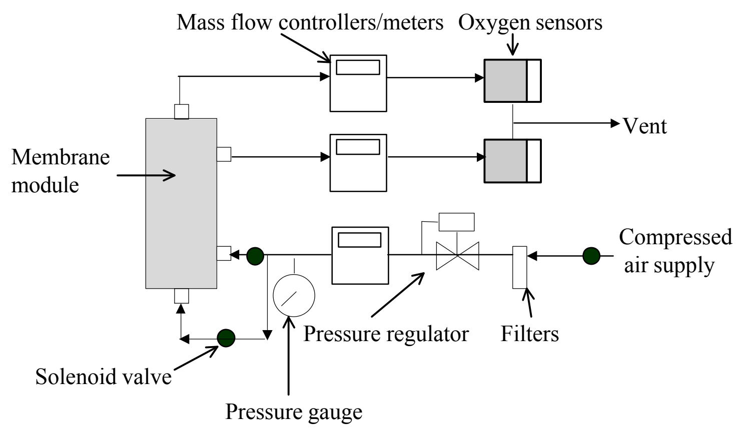
the shell (right hand side port) of the module. Air enters the module at one end and flows to the other. As it moves through the module, oxygen permeates from the high-pressure feed to the low-pressure permeate. Oxygen permeates faster than nitrogen so the low-pressure permeate is enriched in oxygen and the high-pressure stream is enriched in nitrogen. Module performance is calculated from the flow rates and composition of the product streams and the feed pressure. Students are asked to determine how performance changes with nitrogen purity and if performance depends on whether the feed is sent to the lumen or shell. The results are compared to theoretical predictions.

Figure 3. Membrane gas separation experiment sc hematic.



Oxygen concentrations of the lumen and shell outlet streams are measured with oxygen meters; the feed concentration is assumed to be 21%. The feed flow rate is measured with a mass flow meter while nitrogen and oxygen product flow rates are controlled or measured with mass flow controllers. Pressure transducers indicate the feed pressure. Table 2 contains a list of experimental equipment; data acquisition and control hardware are identical to that in Table 1.

The compressed air supply comes from a laboratory compressed air line that is maintained at ~90 psia. The product streams are mixed to produce a gas with the same composition as the feed and vented to the room.

Table 2. List of experimental equipment for the gas separation experiment.

Quantity	Item	Manufacturer	Model #
1	Gas separation module	Permea	PPA-22AD
3	Oxygen sensors	Engineering Systems & Designs	Oxan 600
3	Mass flow controllers	Omega	FSK 8131

Audio/Video Transmission

A number of options for providing live audio and video of the experiment were considered. These are summarized in Table 3 along with the relative advantages and disadvantages of each.

The options offer a wide range of tradeoffs. The $15,000 Polycom ViewStation FX was the clear winner in terms of image quality and network delay but at significant cost. RealNetworks offers very good image quality but the network delay was disconcerting. In preliminary tests the results of executing a control action were visible in the VI front panel well before the audio signal associated with the action was sent. Network delay is low with NetMeeting but the image quality was the poorest.

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Table 3. Options for providing live audio and video of the experiments.

Option	Video Image Quality	Network Delay	Cost
RealNetworks RealOne Player, Helix™ Universal Basic Server, Helix™ Producer Basic	Clear and crisp video image	10-15 sec	Free
NetMeeting	Somewhat fuzzy	1-2 sec	Free
Polycom ViewStation FX	Superior	0-1 sec	$15,000
Polycom ViaVideo Desktop Host and client require similar equipment	Clear and crisp	1-2 sec	$599

We believe the quality of the signal will have an impact on the educational effectiveness of the labs and plan on studying its impact. For our initial work, though, we selected NetMeeting because it provides the closest to real-time signal with no additional cost. When running the experiment, students open a web browser and NetMeeting and connect both to the control computer.

Assessment

The dialysis experiment was used Fall 2002 in Lab II at the University of Toledo. Students were selected at random to run the experiment either through the Internet or hands-on – approximately 18 students ran the experiment in each delivery mode. At the conclusion of the laboratory, focus groups were organized to gather preliminary feedback on student response to the experiment. This feedback will be used to develop surveys and guide interviews for future assessments. General observations from the focus groups are reported first then specific observations related to student: (1) motivation, (2) comfort, (3) collaboration, and (4) perception of authenticity.

General observations. Overall, students reported little difference between performing experiments through the Internet or hands-on. They commented that they enjoyed having the opportunity to perform an experiment remotely and would like to have additional experiments mixed in with the hands-on ones. However, they also felt that Internet-delivery would not work for certain experiments, in particular those that require sampling and analysis of the samples or possess important visual components such as the observation of flooding.

Some students felt that the Internet-delivered experiment was quicker and easier because data collection was automatic. However, one student commented that this made him uncomfortable because he trusts his own work more, especially calibrations of key pieces of equipment.

Many students commented on the poor quality of the video signal. The low resolution prevented them from seeing details of the equipment. Additionally, some students were unable to get NetMeeting to work.

Students reported that an instructor or other staff member must monitor the experiment and be available for assistance if a problem occurs. For instance, one group had difficulty running the experiment and walked over to the lab to determine the problem. They discovered that a line had become disconnected and were able to fix it easily. This could not be done if the experiment was located at another university.

Student motivation. Most reported that they enjoyed the Internet-delivered experiment just as much (or as little) as the hands-on experiments. The most important consideration to them was not how the lab was delivered but its content. Whether it is remote or hands-on, students still must perform the data analysis which is the hard part. Some said they enjoyed the Internet-delivered experiment less, because they could not view the equipment clearly, but commented that it was important to perform an experiment remotely.

Student comfort. Most reported that they were just as comfortable performing the Internet-delivered experiments as the hands-on ones. Some commented they were more comfortable while others commented they were less. One student said he trusted his own work more. A few others were uncomfortable with the computer program. They reported that they were not confident saving the data and had problems retrieving it at the conclusion of the experiment. Additionally, they reported some confusion with the user interface.

Student collaboration. Some students felt the level of collaboration was not affected by Internet-delivery. Others reported less involvement – a few students would take the lead in doing everything, because one person enters information into the computer. However, they also commented that the experiment itself might have influenced involvement.

Student perception of authenticity. Most students felt the Internet-delivered experiment was as authentic as any other lab. They said the nature of the lab is more important than its delivery. One student even commented that a remote lab was more like industry. Some students were uncertain about the experiment's authenticity. They commented that the remote lab was not as authentic due in part to not being able to clearly view the experiment.

Conclusions

The development of two Internet-delivered Unit Operation Laboratories in membrane separation processes is described. We believe the use of such labs in the curriculum can offer significant pedagogical and financial benefits if they provide an appropriate learning experience. The dialysis laboratory was used in the University of Toledo's Lab II Fall 2002. Student reaction to the lab is reported. The response is generally favorable in terms of student motivation, comfort, collaboration, and perception of authenticity. However, specific opportunities for improvement were identified including the quality of the audio/video signal, experiment reliability, and user interface; improving the video signal may necessitate significant additional cost based on the options evaluated here. Somewhat surprisingly, many students that offered negative feedback also stated they felt it was important to have experience running experiments remotely. We believe a combination of remote and hands-on labs will ultimately improve laboratory education.

References

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