34th Australasian Association for Engineering Education Conference
3 - 6 December 2023 – Gold Coast, QLD

On-campus, pilot scale experience for undergraduate engineering students

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CONTEXT

The Department of Chemical Engineering at Monash University has implemented an on-campus student-run pilot plant based on a water treatment process using conventional membrane technology. We are integrating the pilot plant into our undergraduate curriculum across all year levels in Chemical Engineering, and also in relevant units in other Disciplines. Working with the pilot plant will enable students to apply the engineering concepts and principles to a real process in a controlled environment, and equip them with the practical skills they need to succeed in their professional careers.

PURPOSE OR GOAL

Integrating pilot plant training into undergraduate chemical engineering courses offers several advantages. It provides hands-on experience with industrial-scale equipment and processes, bridging the gap between theory and practice, helping students understand the complexities and challenges of real-world chemical engineering operations. It enhances students' system thinking and problem-solving abilities by allowing them to troubleshoot and optimize processes in a controlled environment. It also fosters teamwork, communication, and critical thinking skills as students collaborate on projects and face practical challenges together. Pilot plant activities familiarise students with industry-standard practices, safety protocols, and regulatory compliance, preparing them for future professional roles in the field.

APPROACH

We are currently working on integrating the pilot plant into the curriculum at levels 1-3 by supplementing of replacing current practical activities with pilot plant analogues or developing new activities that align with the unit learning outcomes.

ACTUAL OR ANTICIPATED OUTCOMES

We hope to improve the student experience of undergraduate laboratory activities. We plan to collect comments and feedback via the standard student surveys run by the University, which include quantitative and qualitative questions related to the standard of the unit.

CONCLUSIONS/RECOMMENDATIONS/SUMMARY

We hope to show that the implementation of pilot plant labs improves the student experience and rating of these units based on past performance. We also hope to show that students develop system thinking and that their grades are positively affected by undertaking scaffolded Pilot Plant activities throughout their degree.

KEYWORDS

pilot plant, authentic laboratory activities, practical skills, hands-on experience

Introduction

For several decades now, learning models have been evolving from formal structures to informal and experiential learning. Theories and the literature support this evolution (Roberts, 2012; Seaman, Brown, & Quay, 2017). Considered from an engineering education perspective, experiential learning makes a lot of sense as engineers learn this way once they get out into the workforce. It's impossible for a formal degree program to provide adequate training for every specific job in which an engineer might be employed, and theories such as the 70:20:10 framework are currently under investigation to help explain and direct this type of education (Johnson, Blackman, & Buick, 2018; Thomas Litzinger et al., 2013).

One of the ways that Universities can improve student learning is to provide authentic experiences that can help students to develop the skills they need to address real world problems, e.g. problem-solving skills (Burkholder, Hwang, & Wieman, 2021), project management (Billet, Camy, & Coufort, 2010) and system thinking skills (Cameron et al., 2019). The specific technical skills learned may not be directly applicable to every role that students may take up upon graduation, but the experiential learning method may serve to equip students with the ability to learn in this way, from their experiences, and to apply that way of learning to their subsequent professional experiences.

Integrating pilot plant training into undergraduate engineering courses addresses many of these aspects. It provides hands-on experience with industrial-scale equipment and processes, bridging the gap between theory and practice, helping students understand the complexities and challenges of real-world chemical engineering operations. It enhances students' system thinking and problem-solving abilities by allowing them to troubleshoot and optimize processes in a controlled environment. It also fosters teamwork, communication, and critical thinking skills as students collaborate on projects and face practical challenges together. Pilot plant activities familiarise students with industry-standard practices, safety protocols, and regulatory compliance, preparing them for future professional roles in the field.

To progress the research in this direction, and contribute to the debate as to how to adequately and accurately assess the efficacy of giving students authentic learning experiences, the Department of Chemical and Biological Engineering at Monash University has implemented an on-campus student-run pilot plant based on a water treatment process using conventional membrane technology. There are several examples of educational pilot plants in Engineering Faculties worldwide, such as University of Seville (Vega & Navarrete, 2019), University of Sheffield (Salman, 2023), University of Surrey (*Fluor Pilot Plant*, 2023). However, there appears to be little research into the educational outcomes being achieved using this scale of equipment in terms of experiential learning.

At Monash, we are integrating a Membrane Pilot Plant into our undergraduate curriculum across all year levels in Chemical Engineering, and also in relevant units in other Disciplines. Working with the pilot plant will enable students to apply the engineering concepts and principles to a real process in a controlled environment, and equip them with the practical skills to apply experiential learning in their professional careers. This paper presents our ideas and progress with integrating the pilot plant and related activities into our curriculum, and foreshadows the ways in which we plan to measure the impact of the pilot plant activities on the student learning experience.

Monash Membrane Pilot Plant process description

The Monash Membrane Pilot Plant (Figure 1) is a water treatment process based on membrane filtration technology. Membrane filtration plays a crucial role in improving process efficiency, product quality, and environmental sustainability in the chemical and process industries. Membrane treatment processes are commonly used in industry for solvent recovery, removal of impurities, wastewater treatment, concentration, fractionation, and product purification. Membrane filtration of water-based solutions and suspensions was chosen as the process for the Pilot Plant as it gives students an opportunity to gain practical skills that are directly relevant to industry.

Figure 1: The Monash Membrane Pilot Plant

The process consists of a number of integrated unit operations that can be combines in various ways depending on the feedstock being processed and the desired product. There is a feed tank, a low-pressure circuit with a pump and two ultrafiltration (UF) membrane modules, a high-pressure circuit with a pump and a single reverse osmosis (RO) membrane module, and several heat exchangers. There is also an automated clean-in-place (CIP) backwash feature on the UF circuit. The UF circuit is semi-automated once the mode of operation is manually configured. The two UF modules can be run individually, or together in series or parallel configurations The RO circuit is run manually. The pilot plant is industrial scale, with full sized membrane modules and a maximum throughput of about 100 L/hr. The process is semi-continuous, with a buffer tank between the low- and high-pressure circuits. The system can be used to remove contaminants or to recover products from aqueous solutions, mixtures or suspensions.

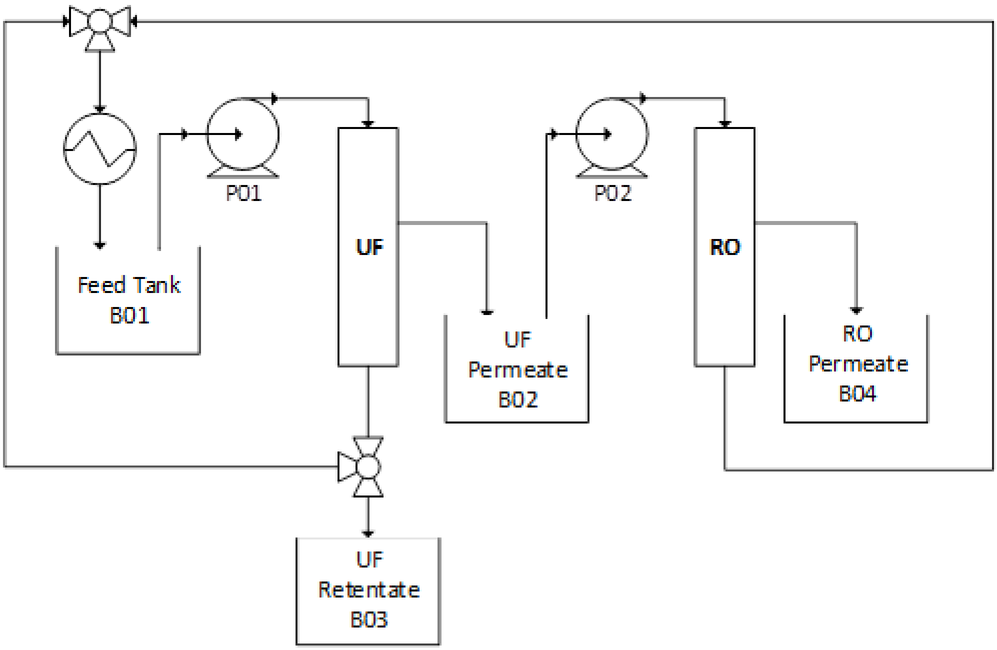

Figure 2: Simplified Process Flow Diagram of The Monash Water Treatment Pilot Plant

In general, the Pilot Plant process operates as follows (Figure 2): a water-based feed solution, suspension or mixture containing contaminant(s) to be removed and/or product(s) to be recovered is prepared and loaded into Feed Tank B01. Pump P01 is used to generate flow and pressure across the UF membrane(s) to filter the feedstock and produce two product streams: the UF retentate and the UF permeate. The UF retentate is either collected in Tank B03 or recycled back to the feed tank via the heat exchanger for reprocessing. The UF permeate is collected in Tank B02. If further treatment of the UF permeate is required, Pump P02 is used to generate pressure and flow across the RO membrane to filter the UF permeate and generate RO retentate. The RO retentate is recycled back to Tank B01 via the heat exchanger and the RO permeate is collected in Tank B04. Depending on the feed and product specifications, any or all of the four retentate or permeate streams collected in the four tanks could be the final product(s) from the process.

Integration into the curriculum – current and future

We are currently working to integrate pilot plant activities across the chemical engineering curriculum at levels 1, 2 and 3, as well as offering use of the equipment to other disciplines within the Faculty of Engineering to enrich the experiences of their students. Activities at levels 1, 2 and 3 are planned to demonstrate the first two, middle two and last two of the levels of learning in the cognitive domain according to the revised Bloom’s Taxonomy (Anderson et al., 2001).

Level 1 activities – remembering and understanding

At level one and two of the Revised Taxonomy, learners should be able to recognise and remember basic facts and concepts related to the field of study, and progress towards understanding those facts and concepts by organising, generalising or summarising them.

Level 1 Pilot Plant activities are predominantly orientation activities using augmented reality (AR) to introduce the pilot plant to students for the first time (Figure 3). This approach has the dual advantage of scalability for our ~800 strong common first year cohort, as well as exposing students to engineering applications of digitalisation technology right from their first year. This activity is offered in the common Engineering Design (ENG1012) unit taken by all first year undergraduate Engineering students at Monash. It has been designed to introduce students to the process that they will (if they choose the Chemical and Biological Engineering discipline) use several more times throughout their course and to help them remember and understand the elements and concepts of an interconnected processes and engineering drawings.

Student undertaking the technical elective Grand Challenges in Chemical Engineering (CHE1010) do a second Pilot Plant activity. This activity relates directly to several weeks of unit content which uses water treatment to introduce chemical engineering concepts to level 1 students. They interact physically with the Pilot Plant to help TAs run a standard experiment in which diatomaceous earth is removed from tap water using the ultrafiltration circuit. Students start and stop the pumps, and collect samples of the feed, retentate and permeate from the appropriate sample valves. They measure the turbidity of the three samples and discuss the mechanism of separation of the solid from the liquid, i.e. size separation. This enables them to see the concepts they are learning put into practice in a real industrial process, rather than simply using (e.g.) a laboratory filter funnel to achieve the same separation. Again, students are learning about individual unit operations related to their degree and learning to remember and understand engineering concepts via an authentic engineering experience.

Figure 3: the Monash Membrane Pilot Plant Augmented Reality Experience

Level 2 activities – Apply and Analyse

At level three and four of the Revised Taxonomy, learners can apply their knowledge and comprehension of facts and concepts, using prior knowledge to implement solutions to problems within their experience. They can analyse the situation according to their experience, organising and differentiating between different solutions to identify the best one.

Two level 2 core chemical engineering units in the curriculum use the Pilot Plant: Heat and Mass Transfer (CHE2163) and Thermodynamics (CHE2164). In Heat and Mass Transfer, students compare the performance of two different heat exchanger configurations. In Thermodynamics, students investigate the isentropic efficiency of the high-pressure pump. In both activities, students study an individual unit operation in more depth, and are given less prescriptive instructions. This encourages them to apply their own knowledge to analyse the given scenario and come up with a way to get the data they need to answer the questions being posed in the activity instructions. For example, one of the thermocouples will be made to behave strangely for students undertaking the Heat and Mass Transfer activity, who will be asked to identify the problem and come up with way that they can operate the equipment safely and generate the data they need without that temperature measurement. Students have to apply their knowledge of heat transfer and thermocouples to analyse the situation and decide how to solve the problem.

Level 3 and 4 – Evaluate and Create

At level five and six of the Revised Taxonomy, learners should be able to evaluate or critique their solutions and generate or create a new scenario or a solution that is not constrained by the given situation. In other words, they have evolved to 'think outside the box' and apply system thinking (ref) to address a complex or interconnected problem that may not have one or even a solution.

The design of the level three activities is currently ongoing. Two activities are planned, in Separation Processes (CHE3165) and one in Process Control (CHE3162). The Separation Processes activity will be centred around students using the membranes to simultaneously recover a wanted species and remove a contaminant from a feed water stream. They will have to recognise that they can't do both simultaneously, and work out a way to do it sequentially using the Pilot Plant. In Process Control, students will be given a scenario-based task in which they will take different professional roles (field operator, control room operator, commissioning engineer) and told to undertake step testing of the process during the commissioning phase. Students will be given context and background, but minimal stepwise instructions for these activities, encouraging them to evaluate the whole system and devise a solution to the given problem.

At level 4, the Pilot Plant is used as part of several Final Year Projects (ENG4701/2). Each Pilot Plant Final Year Project (FYP) has a direct industry partner, adding another element to the learning experience and giving students the opportunity to further develop their professional as well as technical skills. Students are responsible for managing and delivering the project, which is presented as an industry challenge or problem to address or solve. They are given access to the Pilot Plant, as well as technical support and the ability to modify or augment the apparatus to suit their solution to the given problem. This enables students to create their own solution, and raises them to the highest level of the Taxonomy, which would not be possible if not for their exposure to and scaffolding of the Pilot Plant activities throughout the curriculum at all levels.

Research plan

We hope to show that the implementation of pilot plant labs improves the student experience and rating of these units based on past performance. We also hope to show that the student cognition develops towards higher levels as they work through the year levels and undertake the scaffolded Pilot Plant activities, and that their grades are positively affected by comparing with past cohort performance. We plan to collect feedback via the standard student surveys run by the University, which include quantitative and qualitative questions related to the standard of the unit. We plan to collect, collate and compare data to support this hypothesis including:

- Pre- and post-analysis of student reflections on their experience in pilot plant activities
- Multi-year, cohort specific analysis as well as generalised year level analysis, including grade analysis to determine the impact on student performance
- Standard university-run student satisfaction surveys

We already know that the Pilot Plant improves the undergraduate student lab experience based on early, informal student feedback. We are considering conducting pre- and post- analysis via a reflective activity to track the development of student learning as indicated by the students' use of Taxonomy words in their reflections, or by derivation of the Taxonomy levels from the students' reflections. We are also considering looking at the scaffolded activities and student development through the year levels through a systems thinking framework whereby students develop the ability to make sense of complex situations of scenarios, including wicked problems, in terms of a structured whole consisting of related internal and external elements.

We are currently in the process of devising the methodology and combination of methods and relevant instruments that will be applied in this research and applying for ethics approval to present the reflection activities to students undertaking Pilot Plant activities and hope to have asn update to present at AAEE 2024!

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