Chemical Engineering Students Design for Powering the World

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Introduction

The capstone design project is a core requirement in many chemical engineering undergraduate programmes around the world. In this module/course, typically taken in the final semester, students participate in a group project to design a chemical process or product and submit a detailed report. This paper describes the capstone design projects undertaken by students from the Department of Chemical & Biomolecular Engineering at NUS and their reflections on their experiences as well as the challenges they faced.

In the design project, students solve a practical and industrially relevant design problem in the same way as might be expected in an industrial situation. They are expected to develop and evaluate process alternatives via rigorous simulation, perform equipment sizing, optimise various process units, analyse the safety and environmental impact of the process, estimate capital and operating costs, and assess plant profitability. Thus, the design project aims to impart a holistic learning experience, where students get an opportunity to carry out the major steps in the design and evaluation of a new chemical process or product, exhibit creativity, work in a team and write a comprehensive report on a full-fledged chemical process design. Furthermore, students learn how to solve open-ended design problems with several alternate solutions by making critical design decisions based on sound scientific justifications and giving due consideration to cost and safety. Such a learning experience serves to emphasise various aspects of higher order thinking and learning; it also engages students at the top levels of the Bloom's Taxonomy pyramid ("Bloom's Taxonomy", n.d.).

Components of the design project: From conceptualisation to implementation

The design project's topic for each year is different. First, the project statement is conceptualised and prepared well before the project starts; this is done by a team of 6 to 7 academic staff who are the main coordinators for the project which will be undertaken by nearly 300 students. The design project simulates a real-world situation by emphasising a client-vendor relationship reflected in the communications between the teams and coordinators. In addition, practising engineers from Singapore's chemical industry are invited to participate in many aspects of the design project such as formulation of the project problem, presentation of technical talks, meetings with project team leaders and answering queries that students may have.

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Once the conceptualisation is done, students receive the design project statement, including the schedule and deliverables, a few weeks before the second semester begins. They form teams comprising 6 to 7 members, and design a plant with different capacity, feed and/or product specifications. Members of each team are expected to work together on common sections of the project. They are required to submit the minutes of team meetings. In addition, each team member is responsible for designing one of the main sections in the overall large-scale industrial process.

Students are assessed for both individual and group components, based on submitted reports, oral presentations, minutes of meetings and peer assessment. The assessment criteria emphasises the significance and evidence of teamwork, professionalism and communication skills. For peer assessment, each team member evaluates the contribution every other member makes to common sections of the project. Students use standard software in the design project (e.g. Hysys and Matlab for process simulation, and Visio for preparing process flow diagrams). They are required to develop relevant equations, justify the input to the software and/or confirm the results via simplified calculations and qualitatively using first principles[1].

Designing an IGCC power plant

In Academic Year 2010/2011, we challenged our students to design coal-based Integrated Gasification and Combined Cycle (IGCC) power plants, including carbon capture, for different regions in the world. This project topic was chosen in view of the urgent need globally for clean, affordable and sustainable energy. Deemed as “the clean gas technology”, IGCC involves capturing carbon dioxide during the electricity generation process and transporting it to a storage site, also known as carbon dioxide sequestration. A schematic of the IGCC plant is shown in Figure 1; our students were required to design this complete plant.

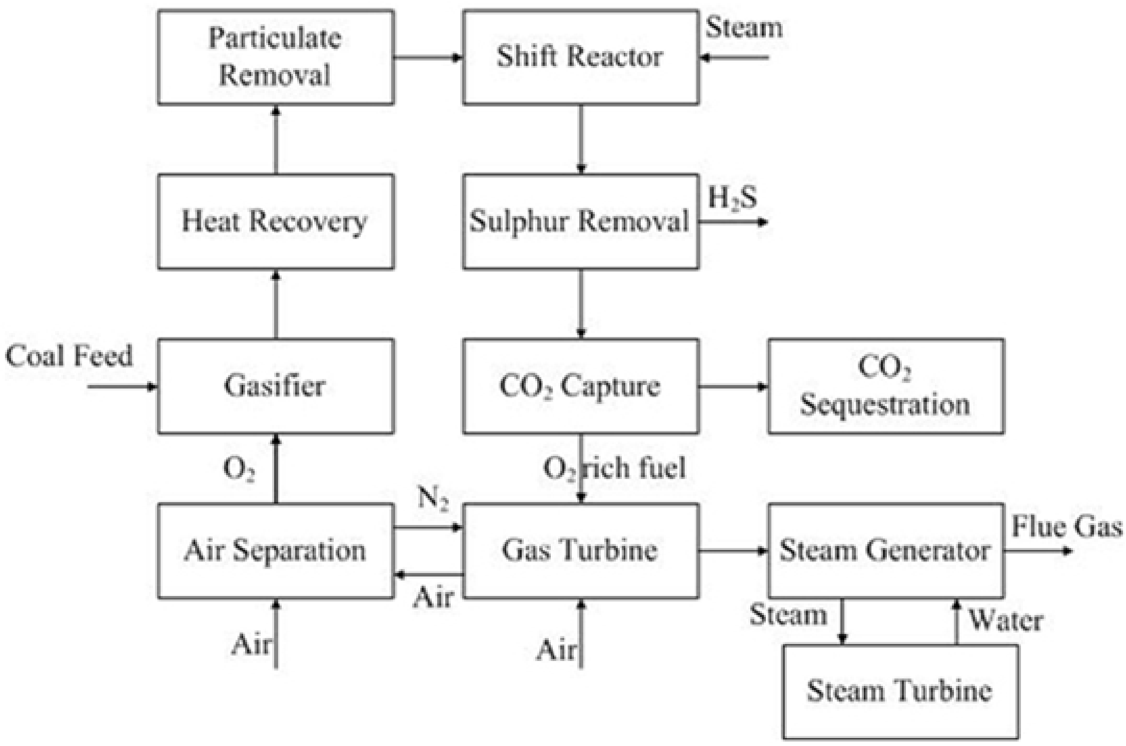

Figure 1. Schematic of an IGCC plant designed by Chemical Engineering students

Each team had to design a plant of specified capacity in different regions of the world, as well as select the feedstock. Table 1 shows the coal-rich regions covered by our students. The teams had to choose the location for their plant in the specified region based on feedstock availability, opportunities for products and carbon dioxide sequestration. They are expected to analyse the sustainability of the plant in that location (in terms of economic, environmental as well as societal aspects) and determine the electricity tariffs the plant requires in order to achieve at least a 10% rate of return on investment over a typical project life of 15 years.

Table 1. Coal-rich regions for IGCC plants designed by Chemical Engineering students

Americas	Europe and Africa	Asia-Australia
USA – South	Russia – East	China – Shanxi
USA – North East	Russia – Central	China – Inner Mongolia
USA – Mid-West	Russia – West	India – North
Brazil	Ukraine	India – South
	Kazakhastan	Indonesia
	Poland	Victoria and Western Australia
	S. Africa – Transval	New South Wales and Queensland

Project outcomes and feedback

In general, students found the design project challenging and required them to extensively apply the knowledge and skills they learnt in earlier modules. The additional benefits of choosing a project topic related to contemporary issues and having students consider how to set up such plants in different regions around the world can be summarised as follows:

- When it comes to the region they selected for their project, students need to familiarise themselves with its geography, rate of industrial development and the existing techno-economic-social conditions. This contextual knowledge provides them with a wider and more global perspective. In the course of doing this project, some students came to recognise the difficulties faced by the manufacturing sector in a foreign environment outside Singapore.
- Students learnt the importance of designing a "green" IGCC plant. Some of them commented that having them select different plant locations enabled them to understand the implications of the environment, regulations, local culture, etc. in the considerations of building a plant. They realised that careful and detailed planning was needed to prevent over-costing.

Not surprisingly, students faced additional and varied challenges due to different plant locations they selected for their respective projects, which informed how their teams developed the technology for carbon dioxide capture and sequestration. For example, teams who designed plants for more technologically developed countries such as USA and Australia found it somewhat easier to obtain information for these regions compared to teams who designed plants for other countries.

At the end of the design project, students were requested to provide feedback on the module and some of their qualitative comments are as follows.

- "In this design project, we applied what we learned throughout our four years of study, acquired what was not known and created something new. This project has indeed equipped ourselves with the confidence and ability to deal with the real industrial design when we start to commence our career in the near future."

- "Yes, as I found this module challenging and believe that it will prepare chemical engineers well for the working environment."
- "The design project as a whole is very interesting and provided me a lot of insight as to how a preliminary plant design can be drafted."
- "Having had the privilege to focus on Russia, it has taught us the difficulties faced by the manufacturing sector in a foreign environment outside Singapore."

Conclusion

In summary, such design projects prepare Chemical Engineering students for the present and future process industry and they have the opportunity to do value addition with minimal adverse effects on the environment. Students get to hone their skills in process design, communication, solving open-ended problems and working in teams through the design project. They get to appreciate the interplay between chemical engineering principles, performance tradeoffs, safety issues, environmental impact and costs as well as learn to handle open-ended problems and uncertain data. Besides tackling these different issues, students have ample opportunities to demonstrate their initiative, creativity and leadership. The need to consider the varied requirements of different regions for the plant locations selected and the topic's contemporary nature provided additional benefits and challenges to students, such as equipping them with increased awareness and a more global perspective, as well as the ability to handle situations where there is a lack of technology and a prevalence of uncertain data. The design project therefore not only helps students integrate domain knowledge and skills but also helps them to frame it in a larger context of cultivating professionalism (communication, team work and ethics), and contributing to societal and global well-being, hallmarks of a truly educated individual.

Endnote

1. First principles refers to one of the fundamental assumptions on which a particular theory or procedure is thought to be based ("The Free Dictionary", n.d.)

References

Bloom's Taxonomy (n.d.). Retrieved 7th February 2012 from *http://www.odu.edu/educ/roverbau/Bloom/blooms_taxonomy.htm*.

The Free Dictionary (n.d.). Retrieved 9th February 2012 from *http://www.thefreedictionary.com/first+principle*. ■

About the Author

Dr Mukta Bansal is part of the academic team coordinating this Design Project for Chemical Engineering students and believes that the best way to engage students is by creating the right environment for them for active learning and to make them feel comfortable enough to open up and interact with their peers and the facilitators.