A PROJECT AND COMPETITION TO DESIGN AND BUILD A SIMPLE HEAT EXCHANGER

Brian Freeland, John M. Tobin and Greg Foley

School of Biotechnology, Dublin City University, Ireland
E-mail: brian.freeland@dcu.ie

ABSTRACT
To address a declining interest in process engineering, a project to design and build a compact heat exchanger was initiated in the second year of a four-year, multidisciplinary degree programme in biotechnology. The heat exchangers had a double-pipe configuration and employed plastic outer pipes and copper inner pipes of various diameters. Designs produced ranged from coiled inner pipes to various multi-pass arrangements and were assessed on the basis of heat transfer achieved per unit mean temperature difference per unit cost. The project, which also formed the basis of a competition, was very well received by students and gave them hands-on experience of engineering design and construction, as well as team work, problem solving, engineering drawing and the use of simple tools. Based on the success of this project, a similar problem based learning approach will be initiated in the third year of the same degree programme and will focus on bioethanol production.

INTRODUCTION
The BSc in Biotechnology degree at Dublin City University is a multidisciplinary programme. Approximately 60% of the course is devoted to the various biological sciences (microbiology, biochemistry, cell biology, immunology and genetics), with the remainder devoted to bioprocess engineering, mathematics and chemistry. Surveys of students have shown that they have been attracted to the degree programme largely on the basis of the biology content and are often surprised by the level of process engineering required. In recent years, it has become increasingly clear that the engineering content of the degree programme, which appears rather pedestrian by comparison with the rapidly advancing, and media-hyped biological sciences, has become less and less popular with students. This is reflected in the highest achieving students choosing to do biology-focused research projects in their final year.

The apparent lack of enthusiasm for engineering amongst students is most obvious in the second year of the four year programme where the links between the engineering syllabus and biotechnology seem to be most tenuous. In that year, the engineering subjects covered include the study of heat and mass transfer, mass and energy balances and fluid flow. While every effort has been made to make these subjects as relevant to biotechnology as possible, there remains a distinct lack of enthusiasm for the mathematical and problem solving approach required in engineering.

To generate some enthusiasm for process engineering, we introduced, in 2006, a 'design and build' project and competition in which students, in groups of three or four, designed, built and tested a simple double-pipe heat exchanger. In addition to generating some enthusiasm for engineering, it was hoped that the project would enhance the students knowledge of heat transfer, improve their ability to work in groups, learn by problem solving, gain experience of producing an engineering drawing, gain some practical experience with tools, piping and fittings and see the role of creativity in the design process. The basic concept for the project was based on the work of Davis [1] in which a similar project was developed for conventional chemical engineering undergraduates.

RESOURCES and METHODS

Project Timetable

The project was set up to run over two semesters. In Semester I, some basic heat exchanger theory was presented. This was followed by a number of design sessions in which the available materials were described and explained and each group came up with a basic concept for the heat exchanger design. Following a tutorial on Microsoft Visio, an engineering drawing of their design was produced which they submitted, along with a short report incorporating a list of required materials and fittings before the semester end. For this purpose, a new library and template was developed for MS Visio containing all the components available to the students. This enabled them to 'drag and drop' most of the components onto the drawing sheet. As a backup, all relevant information was placed on a dedicated website which was also used to update students on scores during the testing phases [2]. The marks awarded for the design report accounted for 25% of an Engineering Principles module delivered in the first semester. The heat exchangers themselves were constructed in the second semester. Each group had two three-hour sessions to construct their exchanger. These sessions were incorporated into the Process Engineering Laboratory module and the marks awarded for the building of heat exchanger were equivalent to two conventional experiments. In addition to the marks awarded, the heat exchangers were also judged as described below and prizes of book tokens (€100 per person for first place, €50 per person for second and €25 euro per person for third and fourth place) were presented.

Materials and Fittings

In the summer preceding Semester 1, a number of prototypes were constructed and all necessary materials and fittings for the construction of ten heat exchangers were ordered. These materials were described and explained to the students in a tutorial in Semester 1. Each group had a choice of inner and outer pipe diameter and their decision as to which combination to use forced them to consider the often competing effects of maximising area, maximising Reynolds numbers and minimising cost and ease of construction. The cost of the exchanger was based solely on the cost of the inner pipe and the options were as outlined in Table 1. Each group was limited to €8 of inner pipe.

Table 1 Inner pipe options and associated cost

Inner Pipe Diameter	Cost (€/m)
8mm	1.20
10mm	1.75
1/2 inch	2.13

The complete list of materials and fitting are given in Table 2. All the fittings used were common plumbing fittings and piping that could be sourced from any builders' suppliers. The pipe used for the outer pipe (110mm or 160mm) was ordinary uPVC Wavin soil pipe. A high pressure cement was used to fix the collars and caps to the ends of the Wavin soil pipe. Under testing it was seen that the glued joints could withstand flowrates up to 15 l/min through the outer pipe and temperatures up to 40°C.

Table 2 Fittings used in heat exchanger construction

uPVC Piping:	**Tectite(Push Fit) Fittings:**
160mm Wavin Pipe	1/2" Straight
110mm Wavin Pipe	1/2" Elbow
Collors & Screw End Caps	1/2" Tee
Compression Fittings:	**Copper (Solder) Fittings:**
1/2" to 8mm Reducing Coupling	1/2" to 8mm
1/2" to 10mm Reducing Coupling	1/2" to 10mm
1/2" Hex Nipple	8mm to 10mm
Brass Fittings:	**Consumables**
1/2" Brass Nipple(75mm long)	PTFE Tape
1/2" Sockets	Plumbers Putty
1/2" Back nuts	High Pressure uPVC Solvent Cement
1/2" Rubber Washers	Plumbers Solder
1/2" Tank Connector	Soldering Flux
1/2" Hose tail	

Assembly Laboratory

Prior to commencing the laboratory sessions, lectures were given on workshop rules and safety. Students were introduced to the different hand tools available to them and their use with various fittings. An example assembly procedure was presented that the students should follow. The groups were encouraged to plan ahead and assign a team leader to distribute work. Each group produced a pipe cutting list from their drawing prior to the laboratory session. This helped to focus the students mind on how to make the inner pipe and thus they required only minimal planning when they were in the laboratory itself. The assembly laboratory was run throughout the second semester during two three hours sessions. Three groups participated at any one time. Each group was assigned a station containing bench space, a Black and Decker Workmate™ bench and a tool box. A list of the tools used for the laboratory can be seen in Table 3.

Table 3 List of tools for heat exchanger construction

Student Use:	6" Adjustable Spanner
Black & Decker Workmate	Vice Grips
Engineers Vice	Assorted Files
Mini Pipe Bender	Assorted Screwdrivers
Pipe Bending Springs	
Rubber Mallet	
Ball Pein Hammer	**Demonstrator Use Only:**
Hacksaw	Electric Drill
Copper Pipe Cutter	Hole Saw
Ruler	Soldering Gas Torch
Measuring Tape	Jigsaw
10" Adjustable Spanner	Belt Sander

Assessment of Designs

The metric, η (W/K-€), used to characterise each heat exchanger was

$$\eta = \frac{Q}{\Delta T_{Lm} C}$$

where Q was the rate of heat transfer in the exchanger, ΔT_{LM} was the log-mean temperature difference and C was the inner pipe cost in Euro. Thus, students had to balance the total heat transfer attainable by the exchanger with the cost. Once each exchanger was constructed it was first subjected to a leak test and after the necessary repairs were made, η was determined on the test rig. The group that achieved the highest value of η was deemed the winner as long as (i) they completed their construction on time and (ii) no major repairs had to be performed after the leak test and (iii) they submitted a satisfactory post-assembly short report [2].

RESULTS

Workshop Safety

Laboratory coats and safety glasses were worn at all times. For applying the solvent cement, solvent masks and latex gloves were also worn. Power tools such as drills and jigsaws were only operated by the demonstrator responsible for the laboratory. Gas soldering was also performed by the demonstrator. However students were allowed to help while wearing temperature resistant gloves.

Design and Construction

One of the aims of the project was to give the students some experience of an engineering design process and production of an engineering drawing. To that end, each group developed design concepts while taking into account ease of manufacture, overall heat transfer and pipe cost as factors. Figure 1 below gives an example of an engineering drawing produced by one of the groups.

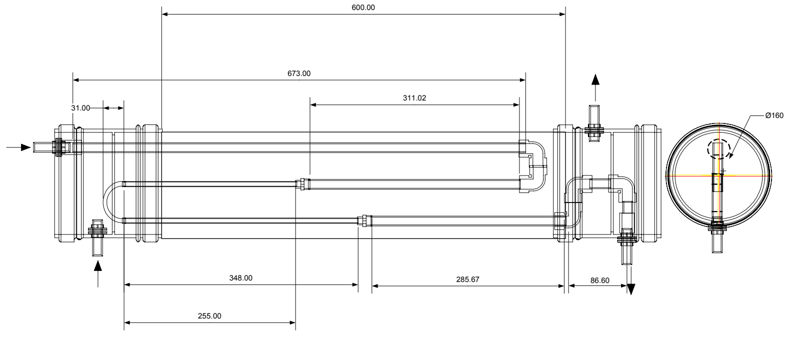

Figure 1 Example of engineering drawing

A variety of designs were produced, varying from simple multi-pass arrangements to coiled configurations as shown in Figure 2 below. Few groups had major problems with leakages, although minor leaks were not uncommon. Generally these leaks were easily fixed by the students tightening the compression fittings, or applying 'plumbers putty' to the interface between the pipe and shell. All groups were able to produce a working heat exchanger within the two three hour lab sessions. Thus, the students acquired the necessary skills to be able to construct their heat exchanger within the given time. This was observed particularly with Group B (see Table 2) where no members of the group had any experience using any hand tools, and had voiced concerns in semester 1 that they may not be able to assemble a heat exchanger. Due to this in semester 1 they focused their design on ease of assembly, and had little trouble constructing their heat exchanger, completing it faster than any other group and coming second in the competition.

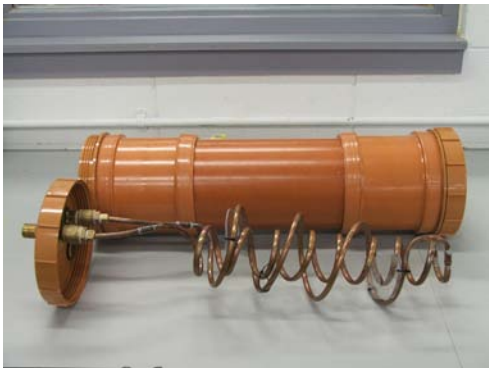

Figure 2a Double coil design

Figure 2b Multi-pass design

Figure 2 Examples of completed heat exchangers

Most groups opted for the 160mm outer pipe (9/10) while 6/10 groups opted for the 8mm copper inner pipe. Three groups used different combinations of ½", 10mm and 8mm pipes in their design. In general the coiled configurations gave the highest total heat transfer due to their high heat transfer area, but because of the cost of the piping, produced smaller values of η as indicated in Table 2. Indeed the winning design was a simple three pass design, entering at one end and leaving at the opposite end as shown in Figure 2b above.

Table 4 Scores achieved by each group

Group	η (W/K-€)	Design
F	21.5	3 pass
B	20.7	2-pass
J	20.5	Double Coil & Baffles
H	19.9	Double coil
I	17.5	Coil
D	14.8	Double Coil
G	13.6	3 Pass
E	12.8	Coil
A	11.4	4-Pass
C	11.3	6-Pass

At the end of the project, a prize-giving ceremony and end of semester 'get together' was held where the various prizes were presented and informal feedback on the project was obtained. Almost universally, the students felt that the project had been an enjoyable experience and one that were keen to repeat in a similar form in subsequent years. Based on this success with problem based learning, it is intended to initiate a project and competition in bioethanol production for the third year class in 2007/2008. The heat exchanger project will also run again.

The success of this project was crucially dependent on meticulous preparation in the summer preceding its first run. In particular, the building of prototypes with appropriate, easy-to-use fittings was essential to ensure that a heat exchanger could be built by an inexperienced student in the time available. For this purpose, technical staff with no engineering training were recruited as test students. Their success with building prototypes, gave confidence that the project was workable within the given constraints.

CONCLUSIONS

The introduction of a hands-on, problem based approach to process engineering teaching has proven to be a popular innovation with biotechnology students. Their appreciation of both the science and art of engineering has been enhanced and the general level of social interaction between students as a consequence of the need for a genuinely group-based approach, has been significantly improved. These and other more imaginative approaches to engineering teaching are essential if students in multidisciplinary degree programmes such as biotechnology are to maintain an interest in the engineering component of their courses.

REFERENCES

[1] Davis, R.A., Chemical Engineering Education, Winter 2005, Vol. 39, p38-42.
[2] Available online at: http://heatexchangerlab.googlepages.com/

ACKNOWLEDGEMENTS

The authors thank the Teaching Committee of the Faculty of Science and Health, DCU, for a Teaching and Learning Innovation grant which funded this work.