DEVELOPMENT OF A HEAT TRANSFER AND ARTIFICIAL NEURAL NETWORKS TEACHING LABORATORY PRACTICAL FOR BIOTECHNOLOGY STUDENTS

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ABSTRACT

The paper describes a newly developed laboratory practical that teaches students how to develop an Artificial Neural Network model and its possible use in bio-processing. An emphasis is placed on giving students "hands on" experience with bio-processing equipment, namely bio-reactors and data acquisition systems in an attempt to help prepare them for work in bio-processing and chemical engineering industries.

INTRODUCTION

The BSc in Biotechnology offered by DCU is a multidisciplinary degree program encompassing Biological sciences and Bioprocess engineering. The main emphasis of the course is directed towards Biological Sciences as 60% of the course material is made up of; Microbiology, Biochemistry, Cell Biology, Immunology and Molecular Biology. The remainder of the course material deals with Bioprocess Engineering, Mathematics and Chemistry. The main bio-processing modules deal with heat and mass transfer, fluid flow and bio-reactor theory. In the past few years it has been observed that students seemed to be more engaged with the new aspects of the biology side of the course. Within the last few years there has been efforts to modernize the engineering laboratory program to engage students and renew enthusiasm for engineering and its applications in biotechnology. To this end in 2006 a "design and build" project was introduced where 2nd year students followed a complete design process; designing and building simple heat exchangers using heat transfer theory [1]. This project was very well received by students, and the "hands on" approach with problem solving requirements at different stages during the lab was well received. In 2007 a bio-ethanol production laboratory practical was introduced for third year students, which was again a "hands on" practical that demonstrated the direction of some bio processing research.

Interest in teaching techniques for engineering has increased over the years. A lot of work as been conducted into how best to present classical theories to students and the skills required by graduates. There is an aim to try and match their learning styles with teaching styles and methods. Emphasis has been placed on how universities equip students for industry. More and more practical based teaching is employed either using virtual laboratories [2] or using full laboratory practical's [3]. In Biotechnology and the processing industries the requirement for graduates to be able to problem solve and work with processing equipment is critical. Therefore hands on experience on processing equipment during their undergraduate studies is a requirement. It was decide to develop a new laboratory to teach heat transfer and the use of bio processing equipment while demonstrating new lines of research in bio processing engineering. The aim of the developed lab would be to help engage students and introduce them to the kind of research being conducted in the school

Heat transfer in stirred tank reactors

Stirred tank reactors are the most important equipment used in biotechnology processing and chemical engineering. They are used for many functions in bio processing such as growing cells, cultures, food production, brewing and for chemical production. They vary in size from 1 litre lab bench scale to 10–30 litre pilot scale to 1000 litres and above for production scale. They can be used in a variety of field's examples of such are; testing new drugs, producing bakers yeast, Bio-ethanol etc. Temperature control is critical for bioreactors as cell growth generate heat that need to be removed, while maintaining the broth within small operating temperatures (30°C–40°C). Due to the significance of temperature control it was decided to examine the overall heat transfer coefficient (U) in a stirred tank jacketed vessel.

Artificial neural networks

Artificial neural networks (ANNs) have been used for diverse applications such as pattern recognition, environmental modelling, machine calibration, chemical engineering and economic modelling. They have been used for several functions such as optimisation, simulation and prediction purposes. The main reason for ANN's use in so many diverse fields is that they have been seen to perform very well in comparison with existing statistical techniques. This is due to their following features:

- Nonlinear/ curve fitting abilities.
- Insensitivity to noise within the data [4].
- Ability to generate acceptable models from limited data [5].

ANNs are starting to be used extensively in heat transfer problems as their abilities stated above make them idea for modeling heat transfer, which in its essence is a non linear problem. The use of Artificial Neural networks for the lab will demonstrate new up to the minute research in bio-processing engineering, as the use of ANNs for heat transfer problems is a very new field, with several papers published in even the last three years [6, 7].

Student Learning Styles

In order to assess the learning styles of a significant sample of the Biotechnology student population, the 2nd year students were given Fielders learning styles questionnaire. The outcome of which would be used to conclude what type of teaching best suits biotechnology students. The survey was conducted on 19 students, 86% of the total class. The survey results showed that 80% of student's surveyed are strongly visual learners, they learn better by reading charts and diagrams to explain concepts rather than presented in a verbal manner. Most of students are balanced between sequential and global, meaning that they like to be presented the full picture of concepts at the start of a lesson and then, introduced to the concept piece by piece. 75% of the class are active learners, with the rest balanced and a small percentage reflective. Its surprising that some students are reflective as studies have show that the engineering and science students are heavily active based learners rather than reflective. From the results of the fielder surveys it can be determined that laboratory practical's and teaching using problems based learning, are techniques that would best suit, biotechnology students. These results also ties in well with general engineering student, who are generally more active and visual learners [8]. Any laboratory practical should be set up in a sequential manner, using a lot of visual aids to explain concepts etc. Students should have a lot of input into the practical, and have a sense of ownership over the practical and their work, this was seen to be a beneficial motivating factor with the design and build heat exchanger project in previous years [1].

Students should be introduced to the following concepts during the laboratory:

- Artificial neural network modelling.
- Experimental setup.
- Heat transfer in bioreactors.
- Industrial specification process equipment; valves, pumps flow meters, data acquisition and computer control.
- Piping and instrumentation (P&ID) diagrams.

RESOURCES AND METHODS

Overall heat transfer coefficient (U)

An equation was developed from 1st principles using heat balance equations to calculate the cooling overall heat transfer coefficient in a stirred tank jacketed vessel. This is used in existing heat transfer lectures and tutorials given in 2nd and 3rd year. Hence the students are expected to know it before they start the lab. They will have to calculate U for their five experimental runs, and the labview program will check their answers, if it's within 10% of actual U, it's saved into the dataset along with the input variables for the given run.

$$\ln\left(\frac{T_0 - T_{w1}}{T - T_{w1}}\right) = \frac{M_w \dot{C}_{pw}}{MC_p}\left(1 - \frac{1}{\beta}\right)t \quad (1)$$

$$\beta = \frac{1}{1 - m\frac{M}{M_w}} \quad (2)$$

$$U = \ln\beta \frac{M_w C_p}{A}\left(\frac{W}{m^2 K}\right) \quad (3)$$

Where: M_w is the Mass flow-rate (m3/s), M is the mass of process Fluid (Kg), N is the agitation Speed (rpm), T is the current vessel bulk temperature (°C), T_0 is the original Tank Temperature (°C), T_{W1} is the input coolant temperature (°C), A is the Heat Transfer Area (m2) and C_p is the specific Heat Capacity of Water (J/kgC). If the correlation is correct a plot of LnT mean Vs time should give a straight line whose slope can be used to calculate Beta Eq.(2) and hence the overall heat transfer coefficient Eq.(3).

Monitored variables and ANN input selection

To calculate U using equation 3 the following process variables must be monitored on the reactor: T, M_w, T_{W1}. In order to develop an artificial neural network model physical inputs were to be selected that were known to effect heat transfer in stirred tanks [9], [10]. These variables had to be monitored and recorded, along with the corresponding U for each experiment in order to build a data set to train the neural network. The selected inputs can be seen in Figure 1.

Why not use existing Bioreactors?
The pilot plant already has 3 fully operational 10l Sartorius Bioreactors. These were not used for the new teaching lab as it would have proven more costly to alter them, adding more process monitoring rather than construct a new one, as sterility of the process fluid will not be an issue, i.e. the product isn't important. Also the three bioreactors are used extensively in research and for 4^{th} year projects, they are critical equipment, therefore the students couldn't get full access to them if used for labs. As one of the main requirements of the practical is to give students experience of using industrial equipment it was decided that a custom made reactor, that has the same operational specifications as a pilot scale reactor should be constructed and used for the lab.

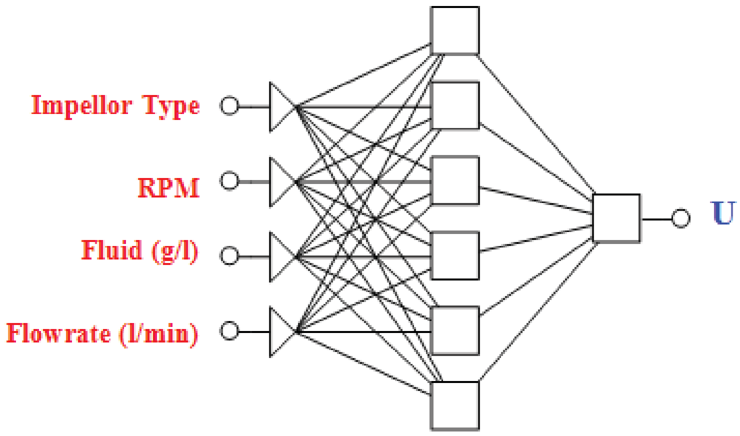

Figure 1: Artificial Neural Network with model inputs and output

Artificial Neural Networks requirements
A base data set was gathered to allow for training of the neural network. A full factorial and central composite design was used to gather a data set with 68 data points. This described the entire operating conditions of the system. The initial base model produced a mean relative error of 5.6% and Max relative error of 10.8%. It's thought that towards the end of the semester the student's model should attain better accuracies than this due to more training data available.

RESULTS

A stirred tank reactor was designed and constructed for the project, using an existing jacketed vessel. The main data acquisition and rig control components are illustrated in Figure 3b. The rig has safety features such as; over temperature shut off and fail safe cut off on all components.

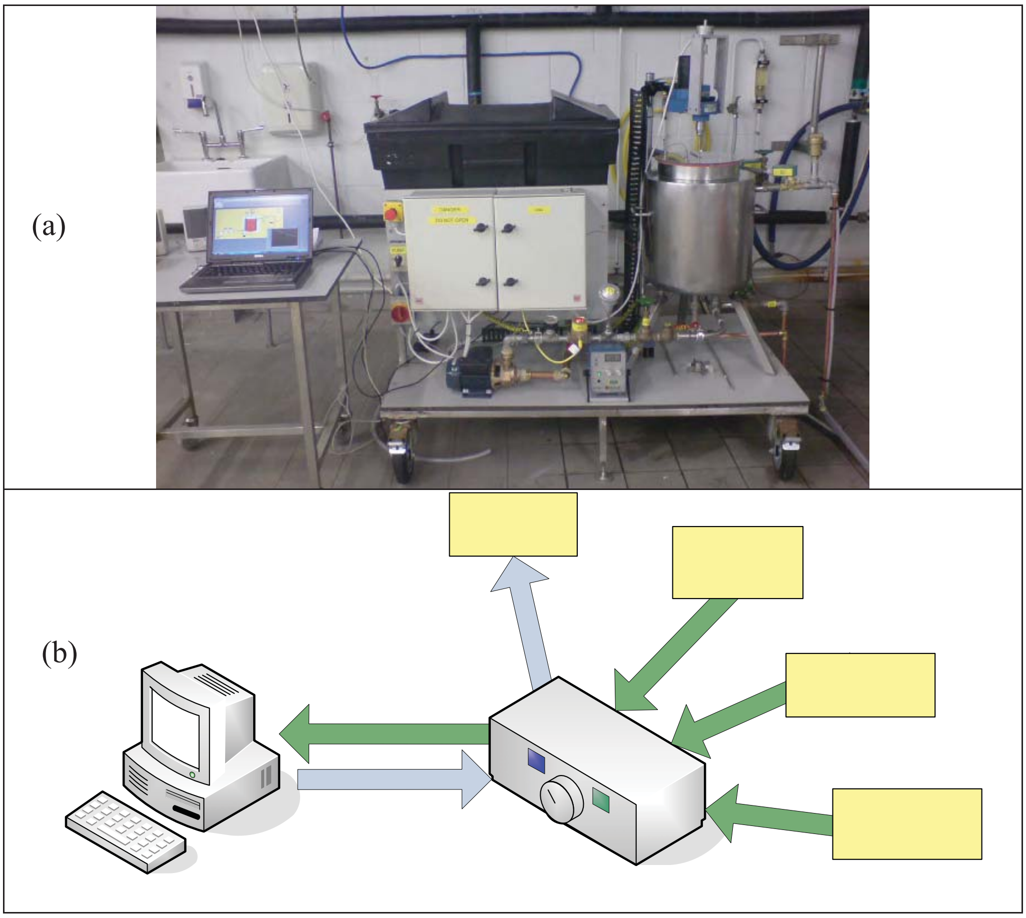

Figure 2: (a) Picture of heat transfer rig and (b) schematic of rig control.

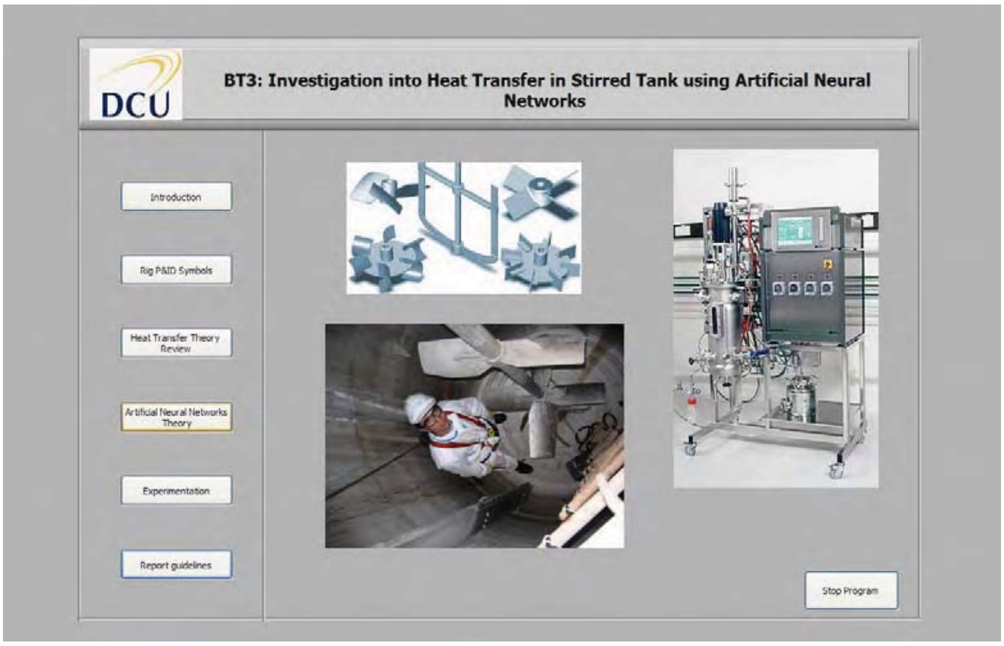

Figure 5: Home welcome screen for laboratory.

Lab Structure (1 day)

The lab is started from the welcome screen in the LabView interface, all options can be accessed from there, except the ANN model development, the uses Trajan neural network simulator software.

1. Review heat transfer theory for bioreactors: Students are given the opportunity to review bioreactor heat transfer theory, this would be a follow on from their lecture notes, however its not parts of the lab as such, just an available resource in the labview program.
2. Piping and Instrumentation Diagrams (P&ID): Students are guided through the symbols for the process equipment on the rig. As part of the report they will have to draw a P&ID diagram for the coolant system.
3. ANN theory: A simplified overview of artificial neural network theory was supplied, this is not meant to go into much detail, and it should help the global learners understand the training process later on during the lab.
4. Show current data set: The students are shown the current data set and asked to decide what five experiments to run that will be added to the data set and aid the development of the neural network, to give a better representation of the operating conditions. Over the weeks as the data set is increased the accuracy of the neural network should increase provided that the experiments are performed correctly. This should demonstrate the online uses on ANN in industry. It would be possible to just give students a full data set and perform an ANN tutorial using that data to develop the models however it was the author's intention to develop a lab that show students a real world Biotechnology application to neural networks and of course to get "hands on" use of bio processing equipment.
5. Show and explain rig and its operation: The labview interface guides through the experimental rig operation and rig settings that can be adjusted when setting up their experiment.
6. Perform experiments: The coolant flow rates, fluid concentration, impellor type and impellor speed is setup, using the labview program, to monitor variables before the data acquisition is started and experiments run. All process variables are displayed on the labview interface during data collection as seen in Figure 5.
7. Calculate the overall heat transfer coefficient: The student calculates U manually from the information given in a data analysis screen. They input their answer, if it's within 10% of the actual (LabView calculated) U its accepted and saved into the data set used for ANN development.
8. Develop the Artificial neural network model from the data set: An additional the lab manual is supplied to demonstrate a step by step approach to develop an ANN model for the data set.
10. Model performance evaluation: The performance of each lab groups developed model is determined during the lab, using mean relative error and max relative error deviation of model output from experimental U. Also towards the end of the semester the last models performance is review by the whole class, to determine what effect the addition of training data had on the modelling performance.

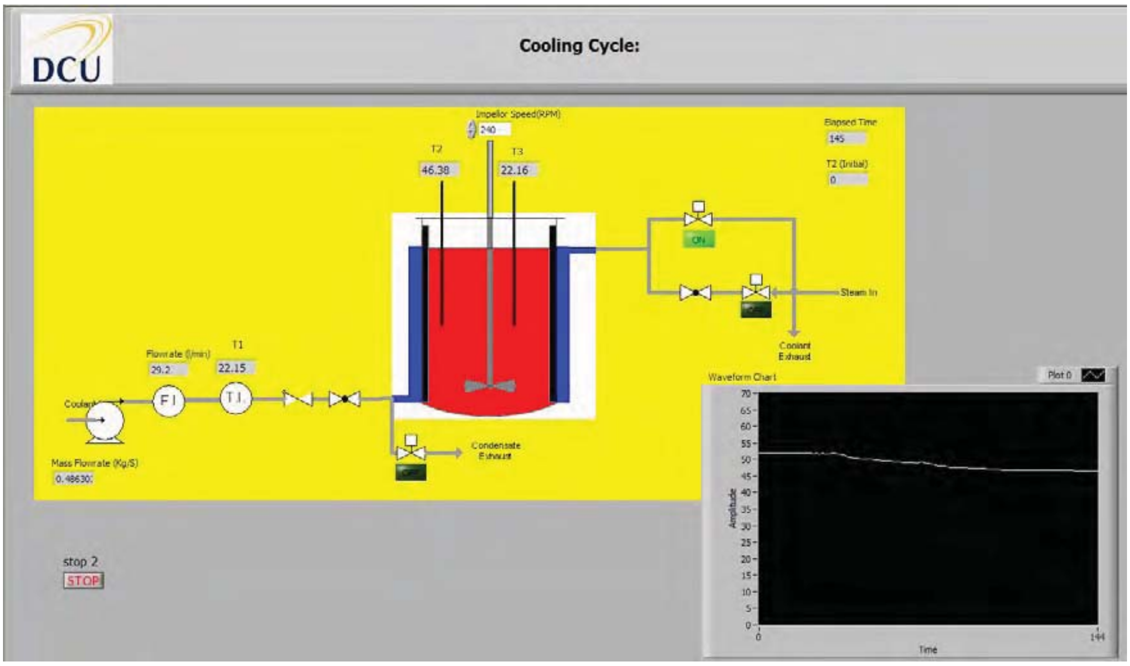

Figure 5: One of the laboratory data acquisition screens.

DISCUSSION AND CONCLUSIONS

A heat transfer rig was designed and constructed using a limited budget. The bioreactors dimensions, operating conditions[11] and components were typical of a pilot scale bioreactor. A budget National instrument card was used very successfully for data acquisition and control of the rig, and a PicoTech TC08 thermocouple data logger integrated successfully into the labview environment. Labview was used successfully to develop a simple user interface that the students should be able to navigate with ease. The interface was set out in a sequential manner, relying on diagrams of the process to illustrate the changing process variables on the rig, an indeed the operation of solenoid valves etc. The students should get a feel for industrial bio processing equipment and the integration of such equipment with data acquisition and control software. Also students should have experienced “up and coming” research within bio processing and see the applications of a research topic, i.e. Artificial neural networks in an industrial setting.

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