1 Executive Summary

Author: M.A. Haji Md. Said

The project was started three years ago (i.e. in 2008) with the aim of converting organic food waste into bio-ethanol. Since it began, three groups of student (with the current group being the third) have undertaken the challenge to research and develop a commercially viable system to convert organic food waste into bio-ethnaol. The developed system was then handed over to the subsequent groups that chose to undertake the project.

Hence upon undertaking this project, the current group acknowledges the fact that most of the basics involved in the production of biofuel applied to this project have largely been influenced and determined by the previous two groups. However, the group did manage to significantly improve the prototype they inherited from the previous groups, despite not being able to do a test run on it due to some health and safety compliance issues.

Research, however, was still done especially in order to further understand the fuel industry and to analyse how organic waste is creating unnecessary problems whenever it can actually be used as 'fuel'. On the subject of recycling and reusing, the group where possible reused as much of the inherited prototype as possible due to the fact that is such a limited amount of budget available for the project. Despite that, the still went over budget in excess of £200 due to some unforeseen expense requirements.

The group improved the whole production system by utilising a domestic flat-packed shelving unit as the main frame of the prototype where all the necessary equipment are technically 'stacked' on top of one another. The only aspect of the project that the group built from scratch are the electrical and electronics control system unit as well as the process control system unit.

Regardless the fact that the project is terminated without properly integrating the control system units together with the structural prototype unit, the group believes that the project can still be considered a success. This is because, despite all odds (i.e. going over budget and not being able to fully finish and integrate the whole system), about 60% of the project objectives were achieved. In addition to that, with all the improvements done on the prototype, the group believe that the aim of fully automating the system is within the grasp of the next few groups who chose to undertake the project and carry on the development.

2 Statement of Originality

We, members of the 2010/2011 Small-Scale Biofuel Production Project Team, hereby declare that the work presented throughout this report is entirely from our own research, except where otherwise indicated in the text. We also declare that our work contains no example of misconduct, such as plagiarism, collusion, or fabrication of results.

Armandas Jarušauskas
[Candidate Number: 56392]

Chitom Obi
[Candidate Number: 10948]

Mohammad Ariffin
Haji Md. Said
[Candidate Number: 10950]

Yuan Qing Yao
[Candidate Number: 16582]

3 Acknowledgement and Foreword

First and foremost, we would like to express our sincerest gratitude to the project supervisor, Dr. Lionel Ripley, for his help, guidance, and encouragement throughout the course of carrying out this project.

We would also like to thank the following people, who are involved (be it directly or indirectly) in assisting us throughout the execution of this project.

- Dr. Christopher Long – the project's second supervisor as well as the Director of the Thermo-Fluids Mechanics Research Centre (TFMRC) for allowing us to use a space inside the TFMRC premises to carry out the project.
- Tim Redmond – for his support, advice on electrical design and help with system tests.
- Kevin Brady – for his patience in helping us during the manufacturing stage as well as his invaluable advice on the solutions to the problems encountered during the modification process to the prototype components.

Finally, we would like to extend our greatest and utmost gratitude to Ray Dadswell, of Eastbourne, for his help, patience, and time to proof read the compiled report.

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4 Scope of Project

Author: M.A. Haji Md. Said

This project is run in collaboration with Achor International (a company based in East Anglia) who focus their research into the development of third generation bio-fuels (Achor International Ltd., 2009). This project is also run in the spirit of tackling the amount of organic waste being dumped into landfills (Awolokun, Adams, Hambos, & Parr, 2009), as well as being driven by the ever-so-present fuel crises (Awolokun, Adams, Hambos, & Parr, 2009), which undoubtedly drive a lot of research on a more sustainable and greener alternative to energy and fuel sources.

The project, therefore, is built with the aim of turning organic waste into usable fuel and energy source. Since the project began two years ago, a working prototype (that is able to produce bio-ethanol) has been built, which includes the processes of hydrolysis, fermentation, and distillation. This prototype was handed down to successive groups who chose to work on it. The project (however) can still be considered to be in its infancy; hence, there is still quite a lot of improvement that needs to be done before the prototype could be deployed commercially. This includes, but is not limited to, the overall efficiency of the system and maximising the automation of the whole system. Further discussions of the work done previously on the project, including the shortcomings of the built prototype, are presented in the subsequent chapters.

The ultimate aim of the project is to build a system that could be implemented within a hotel establishment or on board a cruise-ship or perhaps, within a community and/or neighbourhood, where the amount of organic waste generated is expected to be of significance for the viability of the implementation of such a system.

5 Review of Previous Groups' Work

Author: M.A. Haji Md. Said

This chapter will review the work that has been done by the previous groups to undertake this project, starting with outlining a summary of the work done by the first group of students who started the project two years ago (from here on after identified as Team 08/09), before moving on to look at their recommendations for future work. The chapter would then move on to review the work done and recommendations by the group who undertook the project last year (from here on after identified as Team 09/10).

5.1 Team 08/09

5.1.1 Summary of the Work Done

Awolokum et al (Team 08/09) was the first group to make an attempt on this project about two years ago; hence they ought to be credited for their success in building a working prototype of the small-scale bio-ethanol production system. This enabled their successors to inherit the prototype and continue their research to further improve the system. Credit also has to be given to them for their initial research into this project, which included outlining the processes involved in the production of bio-ethanol, as listed below:

1. Feedstock preparation – this is a process where the feedstock is macerated to prepare it for the next process.
2. 'Saccharification' (otherwise known as hydrolysis) – a process where the macerated feedstock is broken down into simple sugars such as glucose, with the aid of enzymes.
3. Fermentation – in this process the simple sugars are converted into alcohol with the aid of yeast microorganisms.

4. Lastly, 'purification' (otherwise known as distillation) – this final process is where the alcohol produced during the fermentation process is purified i.e. separated from any impurities and collected.

Research done by the group highlighted that the largest component of organic domestic waste is potato (Awolokun, Adams, Hambos, & Parr, 2009). This find influenced their decision to use potatoes as a standard feedstock to minimise any variables, especially for the purpose of testing the functionality of the prototype. This therefore enabled the subsequent groups to do more refined research to try and improve the system.

5.1.2 Summary of Recommendations

Towards the end of their report, titled *"Waste to Bio Ethanol Project"*, Team 08/09 listed a few recommendations towards the future work that needed to be done, especially on improving the system that they had built. One of the major points was to optimise the processes involved within the system and ultimately maximising the efficiency of the whole built system. This include minimising the amount of heat energy wasted by the built system through the different processes (Awolokun, Adams, Hambos, & Parr, 2009, pp. 89-90) and determining the best operating conditions to optimise the effects of the enzymes and yeasts used in the hydrolysis and fermentation processes, which in themselves include researching for the optimal temperature and pH level, amongst others, that is suitable to sustain and maximise the lifespan of the enzymes and yeasts, hence increasing productivity (Awolokun, Adams, Hambos, & Parr, 2009, pp. 86-87).

Team 08/09 also highlighted the potential of incorporating a pH sensor or control system (Awolokun, Adams, Hambos, & Parr, 2009, p. 88) as well as a waste sterilising system into the built prototype (Awolokun, Adams, Hambos, & Parr, 2009, p. 90) in a bid to increase the overall productivity of the built system. The group carried on to analyse the flaws of the built prototype, which includes mechanical circumstances such as problems with the heating elements (Awolokun, Adams, Hambos, & Parr, 2009, pp. 93-94), as well as some unforeseen circumstances within the distillation process – highlighting the unforeseen chemical bonding between the alcohol and water molecules to form azeotropes, which made them very difficult to separate (Awolokun, Adams, Hambos, & Parr, 2009, p. 89).

Furthermore, and perhaps the strongest recommendation suggested by the group was to look into the possibility of producing bio-butanol instead of bio-ethanol, highlighting quite a number of advantages including simpler separation processes, higher energy content and some economical advantages (Awolokun, Adams, Hambos, & Parr, 2009, pp. 91-92). Finally, the group recommended future work to look into increasing the level of automation within the built system in order for the system to be commercially viable (Awolokun, Adams, Hambos, & Parr, 2009, p. 94).

For further details of the work done by the group as well as their list of recommendations, readers should refer to the report written by Team 08/09 titled *'Waste to Bio Ethanol Project'*, a digital copy of which is included in the enclosed disc.

5.2 Team 09/10

5.2.1 Summary of the Work Done

Towards the beginning of their report titled *'Small Scale Biofuel Production'*, Laxman et al (Team 09/10) (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010) researched into the viability of producing bio-butanol instead of bio-ethanol as the final product i.e. as per suggested by Team 08/09 before them. Based on their research, they concluded that producing bio-butanol is not a viable option due to several factors, which mainly revolves around financial restrictions and the complexity of the construction of the mechanical system for collecting the end product (i.e. bio-butanol). Firstly, instead of utilising enzymes and yeasts (for the hydrolysis and fermentation processes), the production of bio-butanol requires the usage of two strains of the bacterium called Clostridium (Awolokun, Adams, Hambos, & Parr, 2009) (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010, pp. 15-17), which are very expensive to acquire. In addition to that, the bacterium could potentially pose a health hazard due to its capability of producing spores (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010, pp. 15-17). Secondly, although the collection of the end product (bio-butanol) would theoretically be much easier as compared to the process of collecting bio-ethanol based on the then current prototype (Awolokun, Adams, Hambos, & Parr, 2009) (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010, pp. 15-17), the bio-butanol (produced using the bacterium Clostridium) would be in a gaseous form, which is commercially known as butane gas. This would mean that a research would need to be undertaken to design, build, and test a system to safely collect and store the butane gas. This, the group thought, was beyond their area of expertise and would, undoubtedly, pose further complications in terms of the construction of the whole prototype (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010, pp. 15-17); thus the group decided to continue the project on the production of bio-ethanol.

Team 09/10 also did research into the current technologies that are available within the bio-fuel production industry today. They firstly looked into the technologies present in the current large-scale biofuel production industry, before moving on to analyse the processes and technologies involved in the production of biofuel within the small-scale biofuel production industry and comparing the systems and technologies utilised within the small-scale production industry to the then current prototype (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010, pp. 17-25).

To their credit, Team 09/10 did manage to improve at least one element of the prototype they inherited from Team 08/09, especially within the distillation system. They have incorporated a reflux distillation process into the distillation system of the prototype, which significantly improved the amount and quality of bio-ethanol produced (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010). In addition to that, the group also discovered an alternative (and better) strain of yeast, which significantly improved the fermentation process i.e. increasing the amount of bio-ethanol produced per unit feedstock fed into the prototype (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010, pp. 29-30). Despite the significant improvements on the prototype they inherited from Team 08/09, the group still believe that there is still quite a lot of improvement to be done to the prototype.

5.2.2 Summary of Recommendations

Following the discussions on the results from the test-run they did on the improved prototype, Laxman et al (Team 08/09) presented some recommendations towards future research to further improve the prototype, one of which is on the potential of expanding the type of feedstock fed into the prototype to include the utilisation of other organic matter including wood-based products, such as paper and card (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010, pp. 112-117). This would consequently mean that research had to be done to identify the type of enzyme required to hydrolyse the different organic matters i.e. to biologically break the organic matters down to simple sugars, before they could be fermented to produce alcohol.

As with Team 08/09 before them, the group also highlighted the potential and advantage of implementing a pH control system, together with an automated pH balancing system to increase the productivity of the prototype (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010, pp. 112-117). The group also mentioned a few areas that could be improved within the distillation system, a summary of which is listed as follows:

- Automating the control of the valves used to control both the flow of condensate back to the Reflux Still and the flow of condensate to the output faucet for collection (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010, pp. 112-117).
- Estimating the heat loss due to the use of copper material for the design of the distillation system, which could potentially affect the effectiveness or precision of the thermocouple used to measure the temperature within the system (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010, pp. 112-117).
- Redesigning the boiler (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010, pp. 112-117) i.e. reducing the size of the boiler and relocating the heating element, so as to avoid the need to add more water before the distillation process could be run.

Finally, the group concluded in their list some recommendations with regard to the general design of the prototype, which include:

- Implementing sealed part connectors as well as sealed wire or lead connectors – this is to enable the system to be dismantled with ease (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010, pp. 112-117), especially for the purpose of cleaning the system after each experimental run.
- Implementing the use of a motor with adjustable speed (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010, pp. 112-117).

For further details of the work done and the recommendations listed by the group, readers should refer to the report written by Team 09/10 titled *'Small Scale Biofuel Production'*, a digital copy of which is included in the enclosed disc.

6 Background Study

Authors: C. Obi, A. Jarušauskas & M.A. Haji Md. Said

This chapter is dedicated on the background study of the biofuel production industry. Discussions in this chapter is divided into four main sections, the first of which looks into the history of biofuel production, which will emphasise the fact that biofuels have been around for ages. The discussions will then move on to analyse the processes involved in the production of ethanol from starch-rich crops, highlighting the different bio-chemical processes involved. The third section will focus on the debate on food versus fuel issues. The chapter will conclude with the analysis of the UK biodegradable municipal wastes.

6.1 History of Biofuel Production

Author: C. Obi

The term fuel is commonly used to refer to any substances that can be used as a source of energy and power, examples of which include biofuels and fossil fuels. Despite having a similar make-up of origin (i.e. both fuel types are derived from biological matter), unlike fossil fuel, biofuels are generally produced from renewable sources such as plant matters and other biomass, which (through their life-cycle) utilises the ever so abundant energy from the sun, converting it to chemical energy via a process called photosynthesis. This embodied chemical energy can then be utilised by the rest of the living world either through physical consumption or any other conversion processes synthesised by mankind (Merrill & Gage, 1978).

Prior to the discovery (and exploitation) of fossil fuels, mankind have been utilising biofuels as a source of energy and power, however, since the mass exploration and production of fossil fuels, the production of biofuel declined significantly as mankind are becoming more and more dependent on fossil fuel.

Since the discovery fire, wood burning (which is the most basic process of extracting energy and power from a primitive type of biofuel) has been practised by ancient civilisation as a source of energy especially for cooking and heating (History of Biofuels - BioFuel Information, 2010). The discovery of electricity and its usage by the likes of Benjamin Franklin in 1752, Alessandro Volta in 1800, Michael Faraday, and Thomas Edison in 1879 (NEED, 2010) however, enabled mankind to discover other potential use of biofuel, thus this emphasised the fact that mankind have been utilising biofuels to generate electricity for ages (History of Biofuels - BioFuel Information, 2010).

There are two main types of biofuels i.e. bio-ethanol and bio-diesel, both of which (as the name suggests) are derived from biological and organic matter such as biomass. Bio-ethanol is an alcohol-based fuel usually used as an additive to gasoline. Whereas the term bio-diesel can be used to define almost every type of liquid fuels that can normally be used as a fuel on its own without any additive. In its pure form, alcohol can be utilised as a source of energy especially for heating, cooking and lighting as well as a major motor fuel (Merrill & Gage, 1978). Two of the most common types of alcohol with a widespread usage are ethanol (otherwise chemically known as ethyl-alcohol) and methanol (methyl-alcohol); both are equally volatile and flammable and have similar physical properties such as odour and are both colourless. This, however, is where the similarity ends because methanol is extremely toxic and is commonly used as solvents and antifreeze in pipelines and windshield washer fluid, whilst ethanol on the other hand, is edible and has been consumed by humans for millennia in the form of fermented and distilled alcoholic beverages (Merrill & Gage, 1978).

In the Automotive Industry, liquefied biofuel has been used since the inception of automotive engine design, an example of which is when Rudolph Diesel (in 1898) introduced an engine designed to run on peanut oil (which have since been dubbed as the Diesel Engine) at the

World's Automotive Exhibition in Paris (www.nrpw.com/history.html). Almost a decade later, Henry Ford became one of the key players in the early movements on the research of alternative fuels when he launched his 1908 Model T Engine that runs entirely on ethanol (www.nrpw.com/history.html).

By the 1920s, biofuels became more and more widely accepted and the industry seemed to have planted their roots alongside the development of the Automotive Industry. The Petroleum Industry, however, interpreted this as a threat and began the development of cheaper, petroleum-based alternatives of automotive fuels (which have since been known as petro-diesel). This led to the decline of the Biofuel Production Industry and by the early 1940s the use of any kind of biofuels seems to be virtually non-existent (www.nrpw.com/history.html).

The World War II era, however, saw an increase in the demand for biofuel due to the difficulty in obtaining (importing) petroleum-based fuels. It was during this period that biofuel-related inventions flourished; this includes the use of alcohol derived from potatoes (ethanol) as an additive to gasoline (History of Biofuels - BioFuel Information, 2010). This is especially the case due to its advantages over Lead (as the additive), which include reducing the amount of pollutants produced due to the reduced octane level and also increasing the number of mileage per unit fuel consumption (History of Biofuels - BioFuel Information, 2010). Britain then became the second country to embrace the concept of mixing alcohol derived from grains with petrol.

Beginning from the twentieth century, the Biofuel Production Industry began to receive greater support especially due to the ever-increasing oil prices and also the increasing concerns towards the effects of greenhouse gases to the atmosphere (History of Biofuels - BioFuel Information, 2010). Furthermore, since the first major oil crisis between 1973 and 1979 (which was due to some geopolitical conflicts), the giant oil producers of the world i.e. members of the

Organisation of the Petroleum Exporting Countries (OPEC) have taken a stance to significantly reduce the amount of oil exports, especially to non-OPEC nations (History of Biofuels - BioFuel Information, 2010). This difficulty encouraged governments and academics alike, to revitalise the utilisation of biofuel as an alternative source of fuel to tackle the energy crises issues (History of Biofuels - BioFuel Information, 2010). An example of which can be seen in the case of Brazil and Argentina, where the usage of biofuel was encouraged to the populations of their coastal metropolitan areas as early as the 1980s (www.nrpw.com/history.html).

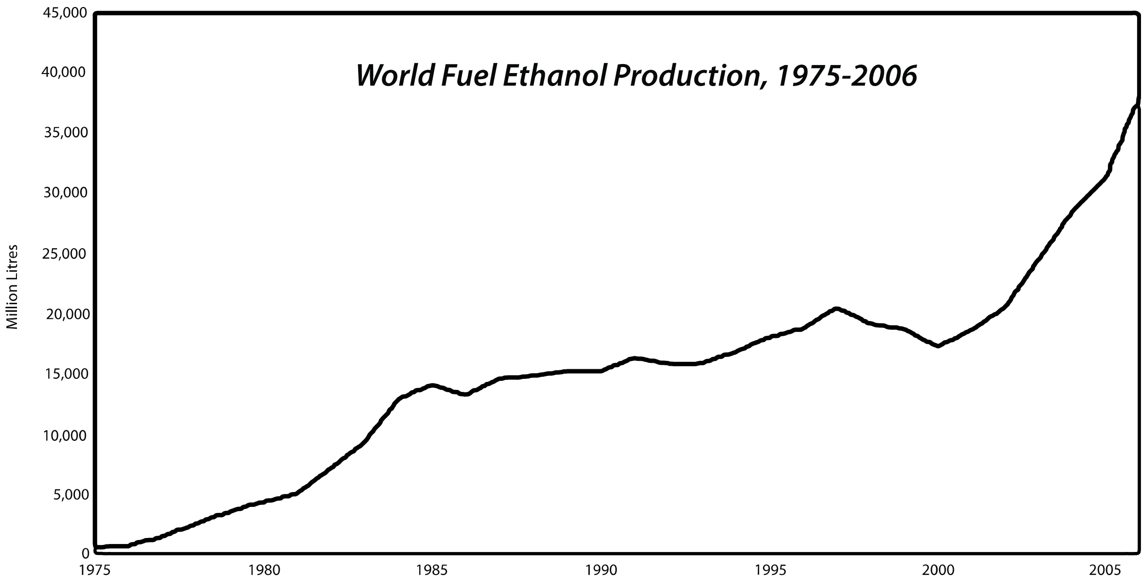


Figure 6.1: World Fuel Ethanol Production, 1975-2006

(Source: F.O. Licht as cited in World Watch Institute, 2007) (Worldwatch, 2007).

On a global scale however, the popularity of biofuel has experienced a significant growth especially in the past nine years as can be seen in Figure 6.1, which illustrates the rise in the production of ethanol between 1975 and 2006. Despite the irregularity in production in the twentieth century, the production of ethanol has seen an almost exponential rise since the year 2000. This can be attributed to the increased awareness of the effect of greenhouse gases on the climate as well as the concerns on the pending consequence of global warming.

The increasing growth in the production of bio-ethanol can also be accounted to the increased activity in the research and developments within the Biofuel Production Industry that have been flourishing in countries such as Australia, Brazil, Canada, China, France, Spain, and Sweden; all of which promote and encourage the widespread production and usage of biofuel such as bio-ethanol (Danielle, 2005). This widespread promotion sees the usage of bio-ethanol as an additive to petrol (in varying percentages), especially for the use as fuel for the Transportation Industry. The world's growing support of the Biofuel Production Industry can further be illustrated with the graph presented in Figure 6.2, which shows the contributions of several countries towards the production of bio-ethanol in 2004. From the chart, it can be seen that Brazil and the United States (US) are the major producers of bio-ethanol, accounting for 38% and 32% (respectively) of the world bio-ethanol production.

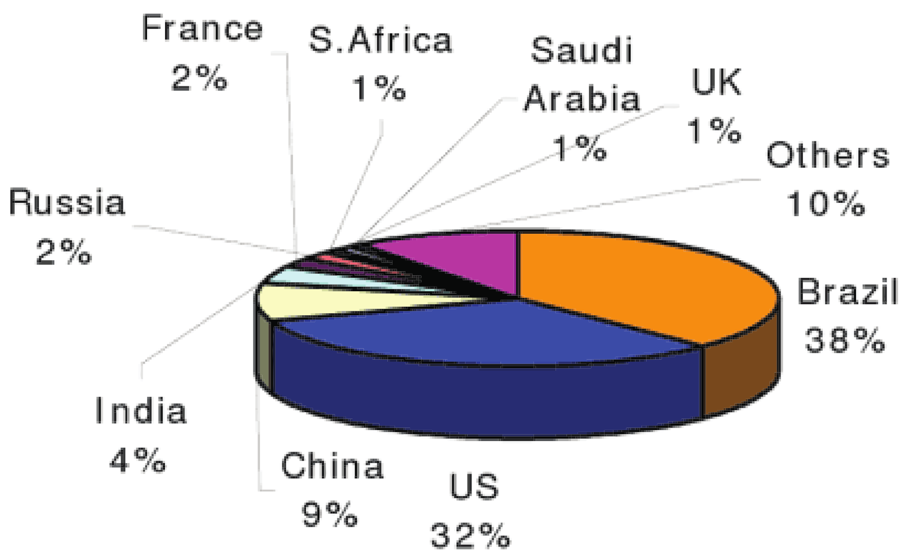


Figure 6.2: World Biofuel Production Contribution, 2004

(Source: F. O. Licht as cited in Murray 2005) (Danielle, 2005).

6.2 Production of Ethanol from Crops with High Starch Content

Author: C. Obi & M.A. Haji Md. Said

In food substances such as carbohydrates, sugar often exists in the form of complex, multi-chain-saccharide (polysaccharides), which are often made up of several simple sugar (usually glucose) molecules that are held together by splitting out water molecules (Merrill & Gage, 1978). Starch is one such example of a polysaccharide (which is mainly found in cereals and potatoes); this is usually the form in which carbohydrates are normally stored in plant matters. In most cases, in order to obtain ethanol from starch, it needs to be broken down into its simplest form (glucose) and the process of breaking down complex polysaccharides is known as hydrolysis, a time-consuming process which can be speeded up with the aid of enzymes. Once the polysaccharides are hydrolysed, it can then be fermented to convert the glucose molecules into alcohol (with the aid of yeasts). Following the fermentation process however, the fermented mixture still needs to be distilled in order to obtain the alcohol. Although prior to any of these processes, the plant matter containing the carbohydrate (or starch) would need to undergo a pre-treatment process where the plant matter is often macerated or even sterilised. All of these processes (pre-treatment, hydrolysis, fermentation, and distillation) will be discussed in greater detail in the subsequent sections.

Throughout this project, the bio-ethanol will be produced using potatoes as the feedstock (for reasons that will be clear the towards the end of the chapter), whose chemical make-up is listed below as described by eHow.com (Demand Media Inc., 1999-2011):

> *"By weight, the average russet potato is about 78.3% water. After water, starches and sugars compose the bulk of the potato's chemical content at about 18%. Non-digestible carbohydrates--or fibre--in the form of cellulose and pectin make up another 0.4% of the potato. Another 2.2% of the potato is protein, 0.1% is fat, and the last 1% is non-organic mineral compounds, mostly in or on the peel."*

As stated previously, hydrolysis, fermentation and distillation are the three main processes that constitute the process of obtaining ethanol from agricultural products (i.e. plant matter), which will be further discussed in the following section and subsections. If the plant matter is a sugar-rich crop such as sugar beets, cane and molasses, which contains high amounts of sugar in its simplest form, then the conversion process into ethanol can be easily accomplished just with the aid of various yeast concoctions (Merrill & Gage, 1978). However, if the carbohydrate is in its polysaccharide form (such as starch or cellulose), it will then need to firstly be hydrolysed into simple sugar before it can be fermented into alcohol (i.e. ethanol).

6.2.1 Review of Bio-Chemical Processes

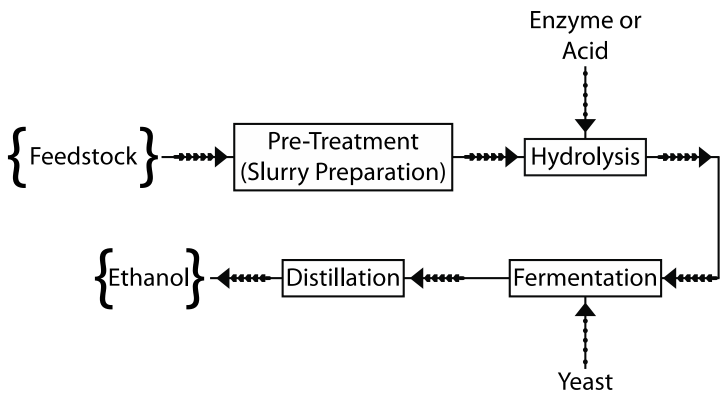


Figure 6.3: Block Diagram of Ethanol Production Process

Figure 6.3 illustrates the basic processes involved in this project, although at this point, it is important to note that a complete conversion of starch into simple sugar and consequently into alcohol is impossible to achieve (Merrill & Gage, 1978). For example, in converting starch into alcohol, by the time the fermentation process is finished about 12-20% of it is lost in one way or another, about 6-10% of the starch remains unfermented, and about 2-3% is converted into glycerol (Merrill & Gage, 1978). Furthermore, a small fraction of the sugar will have been used to feed the yeasts and as a result of evaporation a small fraction of the alcohol will be lost (Merrill & Gage, 1978). Once the entire production processes are complete, the amount of alcohol produced is often calculated in percentage and anything less than 21% of a litre (5.5% of a gallon) per 45 kg (100 lbs.) of starch indicates something is wrong in the conversion processes (Merrill & Gage, 1978).

6.2.1.1 Pre-Treatment

The pre-treatment stage is basically where the feedstock (i.e. potatoes in the case of this project) is prepared for the following processes. This is an essential process because potatoes are rather too large and they need to be made susceptible to enzymatic attack especially during the hydrolysis process (discussed in the next section). An appropriate pre-treatment method (which is cost effective) must be chosen so as to improve the productivity of the hydrolysis process whilst avoiding any degradation or loss of carbohydrates as well as avoiding the production of any by-products that inhibits the processes of hydrolysis and fermentation (Mascia, Widholm, & Scheffran, 2010).

Methods of pre-treatment vary from physical (e.g. grinding and macerating) to physicochemical (e.g. steam pre-treatment and wet oxidation) to chemical (e.g. treatments with oxidizing agents, dilute acid and alkali) to electrical methods (Mascia, Widholm, & Scheffran, 2010). Despite sharing the aim of producing a substrate that is receptive to the hydrolysis and fermentation processes, the characteristics of the substrate produced are highly dependable on the conditions under which any of the previously-mentioned pre-treatment methods are run (Mascia, Widholm, & Scheffran, 2010). The pre-treatment methods that will be used in this project however, have generally been determined by the previous groups to undertake the project, i.e. a physical process that produces a slurry, where the potatoes are macerated (with the aid of water in a 1:1 ratio) using a domestic food waste disposer (InSinkErator) that they acquired and implemented as part of their prototype that they handed down to their successors (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010).

6.2.1.2 Hydrolysis

Owing to the fact that (throughout this project) the ethanol will be produced using potatoes as the feedstock, a catalyst would be needed in order to increase the productivity as well as speed up the hydrolysis process, which is a time-consuming process when left to work on its own accord. A catalyst is a substance that speeds up the rate of chemical reaction without itself undergoing any permanent chemical changes (Soanes & Stevenson, 2005). Enzymes as well as acid-base catalyst are two examples of the common types of catalysts, the former of which is a biological enzyme whilst the latter is an industrially manufactured chemical catalyst.

Starch (irrespective of its source) occurs in the form of white granules of varying shapes and sizes, they are usually formed as an organised structure that is insoluble in cold water or alcohol (Felter & Lloyd, 1898). Starch granules that are contained in potatoes have a relatively large size, thus prior to the hydrolysis process the potatoes (biomass feedstock) will need to be pre-treated (as discussed in the previous section). Once the slurry has been prepared, it will then be transferred into an airtight containment vessel where it will be heated (at a constant temperature of about 50°C) and mixed with a concoction of enzyme (a process which is simply known as the hydrolysis process), to break the starch granules down into simple sugar in the form of glucose.

Despite having the previous groups (who have undertaken this project) determine the majority of the processes involved in this project (to produce bio-ethanol), the current group thought the project would benefit from a research into an alternative process of hydrolysing the feedstock i.e. considering the use of acid-base catalysts instead of biological enzymes. However, after a thorough investigation the group found that the enzymatic hydrolysis process has a far greater advantage over their acid-base counterpart, examples of which include greater yield, higher percentage of alcohol (high purity), fewer by-products, and greater controllability (Ratledge & Kristiansen, 2001). In addition to that, due to its corrosive nature, the acid-base hydrolysis comes with corrosion problems and is more expensive to run as compared to the enzymatic hydrolysis process, which operates under a milder conditions of pH 4.8 and a cool temperature of between 45°C and 50°C (Chen, 2010). Hence due to budget constraints (which will be discussed in later chapters), the group thought it justifiable to continue the project using biological enzymes in the hydrolysis process as has been done by the previous groups.

$$\underset{\text{(Cellulose/Starch)}}{[C_6H_{12}O_5]n} + \underset{\text{(Water)}}{[H_2O]n} \xrightarrow{enzymes} \underset{\text{(Glucose)}}{[C_6H_{12}O_6]n}$$

The equation above illustrates the chemical formulae representation of the processes involved in converting cellulose or starch molecules into glucose, where [ ] represents a repetitive unit and 'n' the number of units chained or linked together to form cellulose or starch molecules, this will then be broken down into 'n' units of glucose molecules.

As mentioned previously, polysaccharides such as cellulose and starch are the major constituent of a potato, which (together) accounts for more than 18% of its chemical makeup (Demand Media Inc., 1999-2011). Therefore, in agreement with the previous groups (Teams 08/09 and 09/10), enzymes amylase and cellulase will be required to break both the starch and cellulose (respectively) down into simple glucose molecules. In addition to that a third enzyme called pectinase will also be required (in limited amounts) to aid break down pectin, which is also present in potatoes (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010). These enzymes are the main constituents of the 'enzyme concoction' mentioned previously.

6.2.1.3 *Fermentation*

Once the hydrolysis process is done (which normally take at least 3 hours i.e. based on the trials done by Team 09/10 in running the prototype), yeasts will be blended into the resulting slurry containing the simple glucose molecules and will be subjected to the fermentation process that can take at least 2.5 days (also in an airtight containment vessel); yeast is a microorganism which acts as the catalyst for this process. However, before the addition of yeast into the glucose-rich slurry, the temperature of the slurry must be lowered (cooled) down to around 27°C as the yeasts can never survive at temperatures above 30°C (Awolokun, Adams, Hambos, & Parr, 2009).

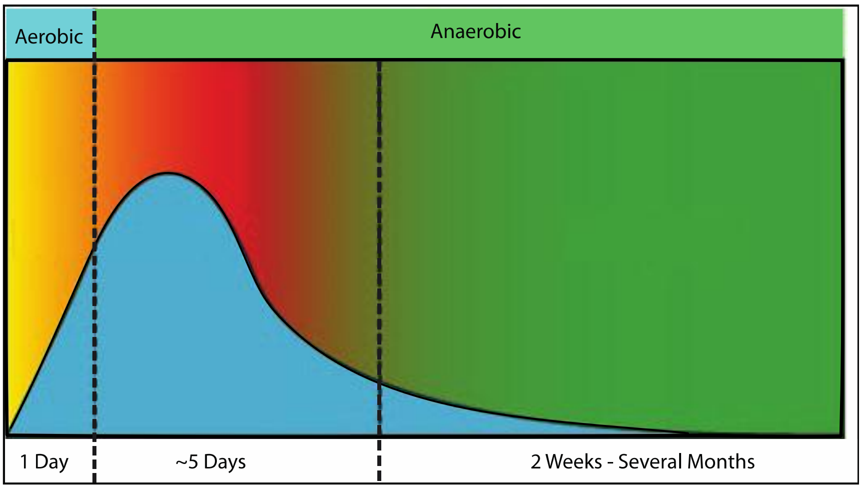


Figure 6.4: Typical Life Cycle of Yeasts.

(As cited by Awolokun et al in '*Waste to Bio Ethanol Project*') (Awolokun, Adams, Hambos, & Parr, 2009)

The fermentation process is basically a series of chemical processes where the output of each process provides the input to the next, the first of which (as can be seen in Figure 6.4) is the growth of yeasts in the presence of oxygen (i.e. an aerobic chemical reaction). This chemical reaction is best illustrated using the following chemical formula:

$$\underset{\text{(Glucose)}}{C_6H_{12}O_6} + \underset{\text{(Oxygen)}}{6\ O_2} \xrightarrow{yeasts} \underset{\text{(Water)}}{2\ H_2O} + \underset{\text{(Carbon Dioxide)}}{6\ CO_2}$$

With six times as much carbon dioxide (a by-product of the reaction) produced per unit glucose utilised, the growth of yeasts can be indicated by the gradual bubbling of the glucose-rich slurry (Merrill & Gage, 1978). Upon the deprivation of oxygen, despite the continuation in the growth of yeasts, the chemical reaction changes from aerobic to anaerobic reaction where the glucose molecules begin to be converted into alcohol and this reaction can be illustrated in the chemical formula below:

$$\underset{\text{(Glucose)}}{C_6H_{12}O_6} \xrightarrow{yeasts} \underset{\text{(Ethanol)}}{2\,C_2H_5OH} + \underset{\text{(Carbon Dioxide)}}{2\,CO_2}$$

The growth of the yeast, however, stops when alcohol is produced to an extent of 5% and this is where the alcohol production begins to peak, a process that can be testified by the rapid bubbling of carbon dioxide (Merrill & Gage, 1978). Throughout the fermentation process, it is necessary to regulate the temperature (of the slurry) so as not to exceed 27.2°C, which can be done by the addition of cold water i.e. an action that not only lowers the temperature and dilutes the slurry but also allows further growth of the yeasts (Merrill & Gage, 1978). This process (anaerobic reaction) will continue until the level of alcohol present in the slurry is beyond the tolerance of the yeasts, a level that varies between each type of yeasts.

6.2.1.4 Purification (Distillation)

Figure 6.5 illustrates the basics of the distillation process, a process that basically rids of any impurity from a mixture of substances (i.e. purifying), it can also be carried out to separate a mixture of miscible liquids by utilising their volatility and with the knowledge of their boiling temperatures. Therefore in order to acquire a specific substance from a mixture of miscible liquids (or liquefied substances), the distillation process would involve heating the mixture up to precisely the specific boiling point of the desirable substance. In the case of this project however, the mixture or fermented slurry will get heated up to specifically the boiling point of ethanol which is at 78.5°C. The vaporised ethanol would then be directed into a cooling chamber where it will get condensed back into liquid form and collected as the final product.

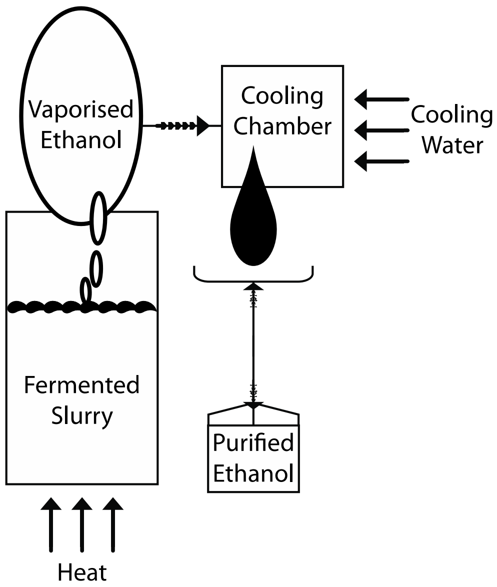


Figure 6.5: Pictorial Representation of a Distillation Process

For a further and in-depth discussion of the different types of distillations and (in fact) for a detailed discussion of the distillation process implemented in this project, readers should refer to the report written by Laxman et al (Team 09/10) (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010, pp. 30-38).

6.2.1.5 Overall Ethanol Production Process

The overall process of the ethanol production involved in this project can therefore be described using the illustration in Figure 6.6.

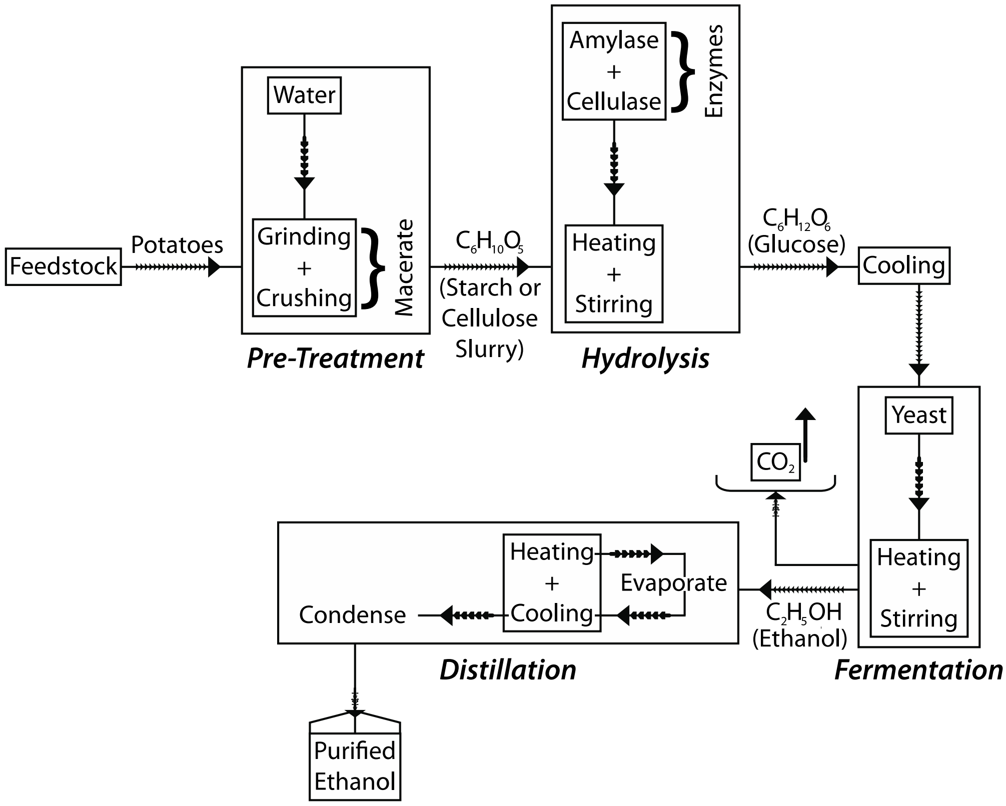


Figure 6.6: Overall Ethanol Production Process

6.2.2 Potential Threat of CO_2

In actual fact, there is more than one way of producing ethanol, all of which depends on the type feedstock used; one of which includes the gasification of ethylene. However, as per discussed in the previous sections, the production of ethanol from agricultural products mainly involves the processes of hydrolysis, fermentation, and distillation (Figure 6.6). As per discussed in the previous sections, the fermentation process produces carbon dioxide (i.e. a colourless, odourless gas which concurrently is also a very famous greenhouse gas) as a by-product that is not only undesirable but may also be hazardous to humankind if present in high concentration. Hence extra attention is required to monitor the fermentation process especially on the level of carbon dioxide present in the immediate atmosphere surrounding the fermentation vessel. This is especially the case due to the fact that this project is run in a closed enclosure within the university premises, where the possible risk of carbon dioxide poisoning must be assessed and in retrospect a preventative measure must be taken to avoid any casualty.

Carbon dioxide (as mentioned previously) is a colourless, odourless, and non-irritating gas, which in small doses does not pose a threat to any living creature. It is commonly used as an additive in carbonated soft drinks or as a shield barrier for welders during their welding work as well as a substance commonly used in fire extinguishers because of its ability to displace oxygen from the incendiary environment (Finne, 2001). Carbon dioxide (CO_2) poisoning occurs due to the exposure to high concentration of CO_2 for an extended period of time, which may cause tiredness or even unconsciousness and in extreme cases it may results in death; this is because the build up of CO_2 displaces the oxygen present in one's respiratory system, which eventually may cause asphyxiation.

Hence, to prevent the occurrence of any carbon dioxide poisoning while carrying out this project, one must ensure that he or she does not stay at the fermentation site for an extended period of time in a sitting position. A carbon dioxide sensor would also be beneficial, but due to the fact that this project is only based on a small-scale bio-ethanol production, incorporating the sensor might not be that practical a step, especially considering the limited budget available. Also the carbon dioxide produced during the fermentation process could potentially be channelled to the exterior of the premises through an air duct or even collected for other use.

6.3 Biofuels and Ethics

Author: A. Jarušauskas

Even though biofuels have been around for nearly two centuries, they have been given more and more attention of late as fossil fuels are getting scarcer and humans become concerned with the environmental impact of our current way of living, where certain people and organisations promote biofuels as a solution to all problems whilst others point out the imperfections of such an approach. This section discusses the ethical aspects of biofuels and what can be done to make this new source of energy more attractive both in the social and environmental terms.

6.3.1 Food vs. Fuel

One of the first approaches to biofuel production utilises agricultural crops such as sugar canes, sugar beets, and wheat as a feedstock. Such feedstock (just as any other agricultural crops) requires land and water. This will undoubtedly lead onto the alteration of the Agricultural Industry resulting in biofuel farmers working alongside food-producing farmers, and who knows what effect this is going to have on the consumer? Some speculate that a direct competition between food and biofuels could result in decreased food availability. There already is food shortage in some parts of the world, so using precious resources, such as land and water, to make energy does not seem to be ethical.

Another problem introduced by such competition is an increase in food prices. The market obeys the law of supply and demand. If the demand suddenly doubles, the prices could quite easily double too. Surely this would have an adverse effect on some people especially the poorest population in the world. If businesses continue to look for ways to increase their profits and starts acquiring their feedstock from farmers in the developing countries, the increase of food prices and decrease in availability may well lead to a global starvation.

6.3.2 Greenhouse Gas (GHG) Emissions

Alongside the *'Food vs. Fuel'* debate, there are also concerns about the increase in greenhouse gas (GHG) emissions resulting from biofuel production. When considering how "green" a biofuel is, one needs to take into account not only the direct effect of using the fuel, the effect of producing it should also be taken into account and this includes growing, transporting, and processing the feedstock from raw material into the desired biofuel. Some even argue that effects from direct and indirect change of the land usage must also be taken into account (Schubert, 2009), a fact that is highlighted by Scharlemann and Laurance in an article titled *'How Green Are Biofuels?'* (Scharlemann & Laurance, 2008):

> *"The findings of Zah et al. are striking. Most (21 out of 26) biofuels reduce greenhouse gas emissions by more than 30% relative to gasoline. But nearly half (12 out of 26) of the biofuels–including the economically most important ones, namely U.S. corn ethanol, Brazilian sugarcane ethanol and soy diesel, and Malaysian palm-oil diesel–have greater aggregate environmental costs than do fossil fuels. Biofuels that fare best are those produced from residual products, such as biowaste or recycled cooking oil, as well as ethanol from grass or wood. The findings highlight the enormous differences in costs and benefits among different biofuels."*

In addition to that, the estimated amount of GHG emissions and environmental impacts varies significantly between different types of biofuels; this can be seen from Figure 6.7. At this point, it is worth pointing out that despite the fact that ethanol produced from potatoes (i.e. the main feedstock used in this project) are presented as having almost a 500% total environmental impact and close to 100% GHG emissions, the ultimate aim of this project is to utilise bio-waste as the feedstock.

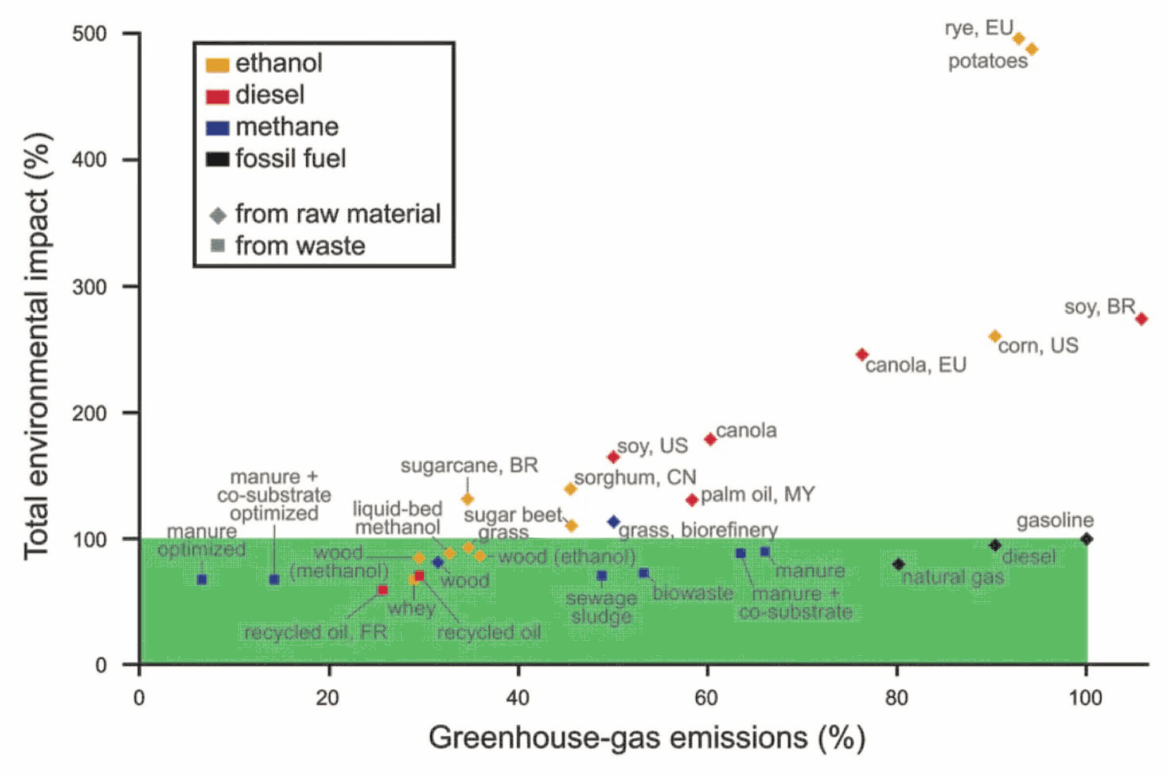


Figure 6.7: Estimation of Greenhouse Gas Emission vs. Environmental Impact

Source: (Scharlemann & Laurance, 2008)

The problems presented in the previous paragraphs mean that further development is still very much of the essence before a viable solution to energy problems can be found.

6.3.3 Second Generation (2G) Biofuels

Many problems created by the first generation biofuels are tackled by the second-generation (2G) biofuels. Most of the feedstock utilised for the 2G biofuels does not come from food materials of which includes waste biomass, woodchips, and straw (Maxwell, 2009). This consequently means that the 2G Biofuel Production Industry does not compete with Food Industry. As mentioned previously, the main aim of this project is (technically) to create a second-generation biofuel with biodegradable municipal waste (BMW) as the feedstock. This (the group thought) contributes to the alleviation of the problems debated in *'Food vs. Fuel'* as well as reducing the total environmental impact and GHG emissions of the production process.

Due to the fact that 2G biofuel productions utilise waste materials as feedstock, the effects on Food and Agricultural Industry is kept to a minimum. In addition to relieving the 'competition against food' problems presented in the *'Food vs. Fuel'* debate, this solution is also very desirable in terms of reducing the amount of BMW generated in developed countries such as the United Kingdom (UK), reasons of which will become clear in subsequent sections. This is due to the fact that when left to decompose in landfills, the waste would generate masses amount of GHG emissions (SEPA). Therefore the process of creating biofuels from waste (up to the point where it is distributed) could be considered to have little or no net effect on the environment.

Hence, the benefits of 2G biofuels are clear. In addition to keeping food prices low (as energy is produced from non-food crops and waste biomass), projects like this will help reduce the amount of waste going to landfills and consequently help reduce the overall GHG emissions and create green energy.

6.4 UK Biodegradable Municipal Waste Analysis

Author: M.A. Haji Md. Said

This section will look into the analysis of biodegradable municipal waste (BMW) generated within the UK. BMW, as defined by the Landfill Directive cited in the report 'Waste Policy & Landfill Directive' (Environment, Food and Rural Affairs Committee, 2005, p. 20), is waste generated from households or otherwise waste with similar composition to that of households, which is decomposable through anaerobic or aerobic processes. Such waste includes food and garden wastes, as well as paper and paperboard (Environment, Food and Rural Affairs Committee, 2005, p. 20).

The analyses within this section are mostly based on the projects commissioned by (as well as the ones carried out in collaboration with) The Waste and Resources Action Programme (WRAP). WRAP is a government supported, not-for-profit company based in Banbury (WRAP, 2010). The company (established in 2000) aims to divert 8 million tonnes of waste material from landfill, cutting 5 million tonnes of CO_2 equivalent emissions whilst generating £1.1 billion worth of economic benefits to businesses, local authorities, and consumers (WRAP, 2010).

For the purpose of this report, the focus of the discussions will be mainly on analysing the amount of municipal food waste generated in the UK. The chapter will be divided into three parts. The first will analyse the amount of municipal food waste generated within the UK in general, including the food and drink supply chain and/or industry and households. The second part will look into some governmental objectives, policies, and strategies in tackling food waste. The last part will focus more on the analysis of food waste generated within the home environment (i.e. UK households).

6.4.1 Food Waste Generated within the United Kingdom

In 2008, the Cabinet Office Strategy Unit published a report titled 'Food Matters – Towards a Strategy for the 21st Century' as an incentive for the government to bring a more rounded food policy which should incorporate issues on health, food safety, the economy and the environment (DEFRA, 2009). As cited in the report by Lee and Willis (Lee & Willis, 2010), the 'Food Matters' report produced estimations of the amount of municipal food and drink waste generated within the UK, in which the Cabinet Office published the following:

Sector	Amount of Waste Generated (Million Tonnes per Year)
Households	6.7
Food & Drink Manufacture	4.1
Food Services & Restaurants	3.0
Retailers	1.6
Others (including Agriculture & Horticulture Sector, Commercial Food Waste, Hospitals and Schools)	2.6 – 4.6

Table 6-1: Food Waste Estimation by the Cabinet Office; adapted from (Lee & Willis, 2010)

From this extract, it can be seen that over a third (33.5%-37.2%) of the food wasted in the UK is generated within the domestic or home environment i.e. UK households. The 'Food Matters' report also set out four strategic policy objectives for food, one of which focuses on ensuring a more environmentally sustainable food chain (DEFRA, 2009, p. 3). This motivated quite a number of activities carried out towards improving the resource efficiencies in the UK food and drink supply chain, despite the limited data available on the subject; this is due to the fact that extensive research into understanding the amount of food waste generated through the food and drink supply was rather minimal (Lee & Willis, 2010). This led to WRAP commissioning a number of researches, firstly, to give more updated information on the subject matter; and secondly, to investigate the amount of waste produced within the three main stages of the food and drink supply chain (Lee & Willis, 2010) as well as the amount of food wasted through UK households (Quested & Johnson, 2009), a summary of which is as follows:

Sector	Amount of Waste Generated (Tonnes per Year)
Households	8,300,000
Manufacturing	2,591,000
Retail	362,000
Distribution	4,000

Table 6-2: Food Waste Estimate Update by WRAP, adapted from (Quested & Johnson, 2009)

Comparing these statistics published by WRAP in 2009 (Quested & Johnson, 2009) with the earlier estimates in the '*Food Matters*' report, it can be seen that there is a 23.8% increase in the amount of food waste generated through UK households within the period of a year. Whereas (on the other hand) the amount of food wasted within the three main stages of the food and drink supply chain recorded a significant reduction with the retail industry recording the most prominent reduction, i.e. a 77% reduction from the previous estimate. This shows that there is still quite a lot of work that needs to be done to tackle household food waste.

6.4.2 UK Food Waste Objectives, Policies and Strategies

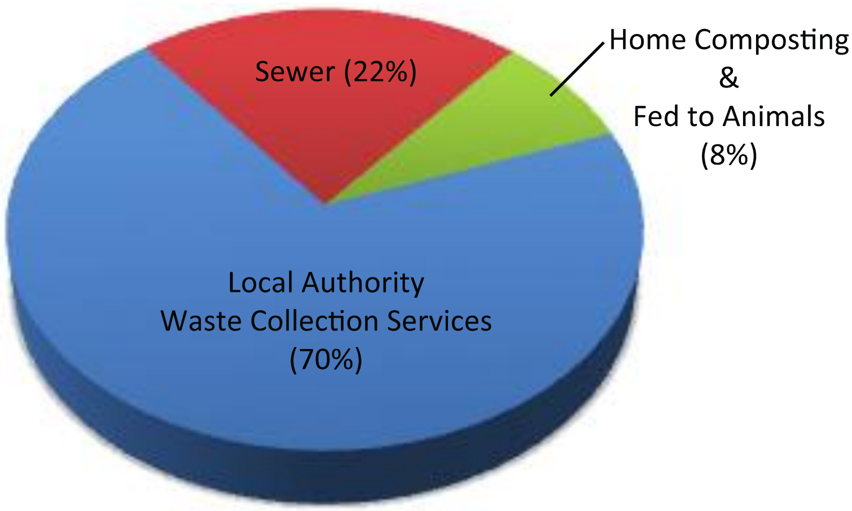


Figure 6.8: Waste Disposal Route, adapted from (Quested & Johnson, 2009).

Expanding on the information from the previous section, the food waste generated through UK household accounts for about 74% of total food waste generated within the UK. Through the analyses done by Quested and Johnson, published in the report titled '*Household Food and Drink Waste in the UK*' (Quested & Johnson, 2009), 70% of the 8.3 million tonnes of household food waste were collected by local authorities throughout the UK (Figure 6.8), in one way or another, bound for landfills. This means that the majority of this waste is unquestionably attainable for the purpose of such projects that aimed to harness its energy as an alternative source of fuel and renewable energy. With the potential of adding another 22%, through effective campaigns and advertising, diverting the wastes disposed of via the sewers (Quested & Johnson, 2009), it could be argued that the potential of harnessing energy and power using this waste is very promising.

Furthermore, in the report Quested and Johnson also estimated that about 64% of the 8.3 million tonnes of the food wasted in the UK was avoidable

(Figure 6.9) – i.e. that which was still edible when it was thrown away or that thrown away whole and unused before the use by date (Quested & Johnson, 2009, p. 32). This (the avoidable waste) is estimated to contribute to an annual greenhouse gas (GHG) emission equivalent to around 20 million tonnes of CO_2 (Quested & Johnson, 2009, p. 28). Perhaps these could be taken as a driving factor in any policies and strategies on tackling the amount of food waste generated within the UK.

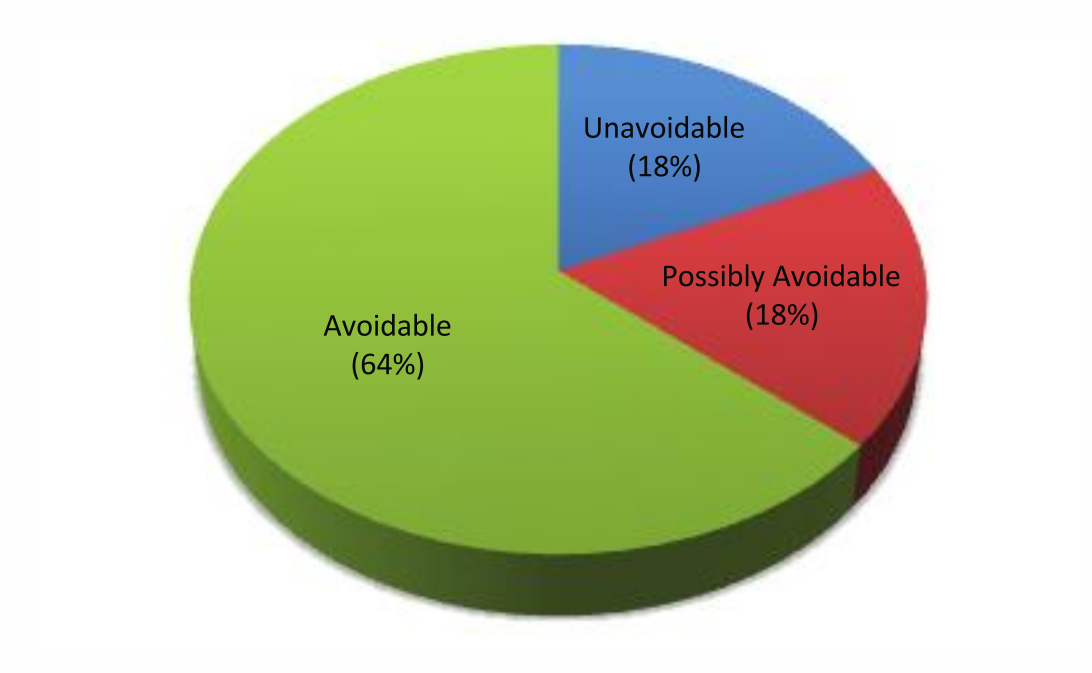


Figure 6.9: Waste Avoidability Estimation, adapted from (Quested & Johnson, 2009).

Having said that, aspirations of diverting biodegradable municipal waste (BMW) from landfills have had been expressed by the UK government; as stated in the report released by the House of Commons, titled '*Waste Policy and the Landfill Directive*' (Environment, Food and Rural Affairs Committee, 2005, p. 20), where the government sets targets to reduce the amount of BMW ending up in landfills i.e. a reduction of 25% by 2010, 50% by 2013 and 65% by 2020 (based on 1995 amounts). In another report titled 'Waste Strategy for England 2007' (Environment, Food and Rural Affairs Committee, 2010, p. 12), the Environment, Food and Rural Affairs Committee (EFRAC) at the House of Commons, is in strong agreement about the idea of banning recyclable and compostable wastes from being disposed of or deposited in Landfills. They (EFRAC) even suggested that the Department of Environment, Food and Rural Affairs (DEFRA) should try and aim to implement the ban by 2015 as opposed to the current target i.e. by 2020. In addition to that, the government have also put some legal frameworks in place with the objective to 'decarbonise' the UK's economy by 2050, as published in their Food 2030 Strategy Report (DEFRA, 2010, p. 43), which includes the 2018-2022 Carbon Budget as well as the Climate Change Act 2008, where the government sets some targets to reduce the amount of GHG emitted to the atmosphere i.e. a reduction of at least 34% by 2022 and 80% by 2050 (based on 1990 emission levels).

Between May 2009 and February 2010, Eunomia Research & Consulting Ltd. did research on the feasibility of Landfill Bans, as commissioned by WRAP, in which they concluded that the benefit of banning biodegradable waste (from landfills) to society, as a whole, would depend on a few issues including the choice of treatments used (which in itself includes the considerations on the costs of building and running of the treatment plants together with that of the treatments of any by-products) as well as ensuring the maximisation of recycling activity i.e. engaging with society and influencing the attitude towards recycling (Eunomia Research & Consulting, 2010, pp. 129-130). In the report it was also concluded that the Landfill Ban would have a significant benefit towards tackling the climate change issues, especially when it is launched with the requirements that waste materials are sorted accordingly (Eunomia Research & Consulting, 2010, p. 129). Furthermore, if successful the Landfill Ban on biodegradable materials is predicted to deliver a reduction of about 110 to 145 million tonnes of GHG emissions for the period of 2009-2024 (Eunomia Research & Consulting, 2010, p. 129).

6.4.3 Food Waste From the UK Households

Focusing the analysis on the food waste generated from the UK households, based on the report published by WRAP titled 'Household Food and Drink Waste in the UK' (Quested & Johnson, 2009), nearly a quarter of the composition of the 8.3 million tonnes of food waste generated in the UK every year is made up of fresh vegetables and salads. In the report WRAP estimated that the composition of the 8.3 million tonnes of food wasted in the UK are as follows (Quested & Johnson, 2009, p. 6):

Food Group	Percentage by Weight	Food Group	Percentage by Weight
Fresh Vegetables & Salads	22.9%	Condiments, Sauces, Herbs & Spices	2.5%
Drinks	15.7%	Staple Foods	2.4%
Fresh Fruit	13.3%	Cake & Desserts	2.3%
Bakery	9.7%	Oil & Fat	1.1%
Meals (Homemade & Pre-Prepared)	8.3%	Confectionery & Snacks	0.9%
Meat & Fish	7.4%	Processed Fruits	0.4%
Dairy & Eggs	7.0%	Other	3.6%
Processed Vegetables & Salads	2.5%		

Table 6-3: Percentage Composition (by Weight) of Food Waste, adapted from (Quested & Johnson, 2009).

Based on these statistics, the group felt that, for the purpose of this project it would perhaps be most appropriate to further analyse the composition of the waste generated under the 'fresh vegetables and salads' group as this group represents the highest percentage of food wasted in the UK households. Upon analysing the statistics published in the same report (as presented in Table 6-4), potatoes were found to contribute up to 40% (i.e. 0.77 million tonnes) of the fresh vegetables and salads thrown away from the UK households on an annual basis (Quested & Johnson, 2009). Hence, in agreement with the previous groups that have undertaken this project, a decision was made that the prototype would be run using potatoes as the feedstock.

Food Type	Percentage by Weight	Food Type	Percentage by Weight
Potato	40.1%	Broccoli	2.1%
Mixed Vegetables	13.0%	Cauliflower	2.1%
Onion	6.8%	Leafy Salad	1.9%
Carrot	6.2%	Bean (All Varieties)	1.5%
Cabbage	4.4%	Pepper	1.2%
Lettuce	3.5%	Leek	1.0%
Tomato	3.3%	Mushroom	0.8%
Other Root Vegetables	2.5%	Spring Onion	0.4%
Cucumber	2.3%	All Other Fresh Vegetables & Salads	4.5%
Sweet corn / Corn on the Cob	2.2%		

Table 6-4: Percentage (by Weight) of Fresh Vegetables & Salads, adapted from (Quested & Johnson, 2009).

On the other hand, upon analysing another research done by WRAP, which was done over a period of 26 months between January 2007 and March 2009, where they supported 19 local authorities in England and two local authorities in Northern Ireland to carry out trials separating the collection of domestic food waste from the collections of other refuse and garden waste bound for centralised treatment plants (Bridgwater & Dr. Parfitt, 2009), the average amount of food waste generated in UK households was found to be 1.31 kg per household per week Table 6-5. Based on this figure, the group felt that the amount of food waste generated by individual households was not substantial enough to pursue and aim the project towards designing a system to be implemented within individual households. Consequently, the aim of the project should therefore be focused on designing systems that would be implemented within an establishment or area with a fairly larger waste catchment opportunity, such as a hotel, a neighbourhood or on board a ship or even perhaps on an offshore structure.

Local Authorities	Avg. Amount of Food Waste Collected (Kg per Household per Week)	Local Authorities	Avg. Amount of Food Waste Collected (Kg per Household per Week)
Belfast	1.09	Mid Bedfordshire	1.89
Broadland	1.84	Mole Valley	1.75
Calderdale	1.28	Newcastle-upon-Tyne	1.14
Croydon	1.64	Newtonabbey	0.53
East Devon	1.79	Oldham	1.22
Elmbridge	1.46	Preston	1.04
Guilford	1.70	South Shropshire	2.10
Hackney	0.32	Sutton	1.38
Kingston-upon-Thames	0.45	Waveney	1.17
Luton	1.12	West Devon	1.48
Merton	1.19		

Table 6-5: Average Amount of Food Waste Collected by Various Local UK Authorities, adapted from (Quested & Johnson, 2009).

7 Projects Related to Biofuel Productions

Authors: M.A. Haji Md. Said & Y.Q. Yao

This chapter will look into such projects that are of similar or related in nature to that of this project. The chapter is divided into two main sections, the first of which will look into the analysis of the results of several case studies where the food waste was collected separately to that of other wastes together with the review of some small-scale electric generation systems. The second section of the chapter looks at some of the technologies (as well as the different projects) available in the large-scale Biofuel Production Industry especially that on the treatments of biodegradable wastes to produce electricity.

7.1 Similar Projects

Author: M.A. Haji Md. Said

7.1.1 Case Studies

The National Industrial Symbiosis Programme (NISP) is one of the many organisations that actively supports the collections and treatments of biodegradable (food) waste in a bid to reduce the amount of waste ending up in landfills. NISP was established in 2005, with the aim of bringing a multitude of industries to work together to improve resource efficiency and sustainability (International Synergies Ltd., 2007), in which they linked several industries together where one particular industry (waste treatment and/or power generation industry) would use the biodegradable waste from the other industries as a source to generate renewable energy (International Synergies Ltd., 2007). To date, NISP has diverted around 35 million tonnes of industrial wastes from ending up in landfills across the UK (International Synergies Ltd., 2007), examples of which includes the following:

- Their success in linking Apetito Ltd. (i.e. a supplier of frozen food and catering solutions) and Andigestion Ltd. (i.e. a power generation company operating biodegradable treatment plant), which resulted in the diversion of 1,700 tonnes of waste from landfill which is estimated to contribute to a reduction of 6,842 tonnes of carbon emissions (NISP West Midlands, 2010).
- Another one of their successful projects involves four organisations i.e. Scolarest (Education Sector of Compass UK & Ireland), Environmental Expressions Ltd, Angelheart Inc. Ltd, and Allensway Recycling; through which they manage to divert around 1 tonne of food waste from school canteens and dinners from landfills, which were treated (composted) by Allensway Recycling (NISP Yorkshire & Humber, 2010). The project also concluded that a typical Secondary School produces around 3 tonnes of food waste annually. In addition to that a similar study by Doncaster Council looking into the amount of food waste generated by Primary Schools also concluded a similar amount; hence it was estimated that around 50,000 to 70,000 tonnes of food waste generated through an excess of 4,000 Secondary Schools and 20,000 Primary Schools throughout the UK (NISP Yorkshire & Humber, 2010).

In addition to that, as a result of the WRAP supported trial on separate food waste collection, several district councils within the UK decided to run a district-wide separate food waste, working with biodegradable treatment plants local to their respective areas to generate renewable electricity; which includes the following:

- South Shropshire District Council worked with BiogenGreenfinch (i.e. a company based in Shropshire which designs, builds, and operates Commercial-Scale Anaerobic Digestion (AD) Plants for processing food waste), making use of around 1,000 tonnes of food waste annually, which would otherwise end up in landfills (WRAP, 2010). Based on the facts published by BiogenGreenfinch on their website (BiogenGreenfinch, 2010), AD is a series of bacterial processes (in the absence of air) which can be categorised into four distinct stages i.e. hydrolysis (where the food waste is broken down to its simplest form such as simple sugar, lipid and amino acids), acidogenesis (where the simple sugars, lipids and amino acids are converted to volatile fatty acids), acetogenesis (where the fatty acids are then converted to acetic acid) and methanogenesis (where the acetic acid is converted to methane which will be used as fuel to generate electricity).

- West Devon Borough Council, on the other hand, worked with Andigestion Ltd. (another company operating an AD plant in Holsworthy); collecting about 9 million tonnes of food waste a week from around 7,500 households (WRAP, 2010).

In conclusion, these case studies show that there is a significant support for and ample resources available on such projects as this.

7.1.2 Small-Scale Electric Generation Systems

In an MSc project at the University of Strathclyde in Glasgow, Currie et al looked into providing information on the availability of renewable energy throughout Scotland (Currie, Elrick, Ioannidi, & Nicolson, 2002). For the purpose of this project, analysis will be focused on small-scale systems utilising biomass including household waste, in which they suggested that the biomass could be utilised as a feedstock for Combined Heat and Power (CHP) generators. An example of this is the utilisation of a range of Farm 2000 Boilers (manufactured by Teisen Products Ltd. based in Redditch, Worcester) capable of producing between 20 to 300 kW of heat, which could be directly utilised in the heating system of buildings including houses and offices, as well as other applications such as heating of public swimming pools.

Lensu and Alakangas carried out a project of a similar nature to that of Currie et al; the findings from their project were published in a report titled 'Small-Scale Electricity Generation from Renewable Energy Sources', in which they did some analysis on small-scale electricity generation systems including Micro/Small-Scale CHP from biomass (able to produce up to 300 kW of energy) as well as Wind Turbines (capable of producing around 3 MW of electricity) and Fuel Cells using renewable energy sources (Lensu & Alakangas, 2004). In the report, they outlined several technologies able to convert biomass to energy, which can be classified under three main conversion categories i.e. biological, chemical and thermo-chemical conversions, each technology producing different products such as bio-ethanol, biogas, biodiesel, bio-oil, fuel gas and heat (Table 7-1). In addition to that, they also listed several small-scale CHP technologies such as Diesel/Gas Engines, Micro Turbine, Stirling Engines, Organic Rankine Cycle (ORC) Turbine and Steam Engine (Table 7-2).

Biomass Conversion		**Product**
Category	**Technology**	
Biological	Fermentation	Bio-Ethanol
	Anaerobic Digestion	Biogas
Chemical	Esterification	Biodiesel
Thermochemical	Fast Pyrolysis	Bio-Oil
	Gasification	Fuel Gas
	Direct Combustion	Heat

Table 7-1: Biomass Conversion Technology, adapted from (Lensu & Alakangas, 2004, p. 27).

<table>
<tr><th rowspan="2">Small-Scale Power Generation Technology</th><th rowspan="2">Combustion Type</th><th colspan="2">Production Capacity</th><th rowspan="2">Feedstock</th></tr>
<tr><th>Electricity (kW)</th><th>Heat (°C)</th></tr>
<tr><td>Diesel/Gas Engines</td><td>Internal</td><td>15-10,000</td><td>85-100</td><td>Bio-Ethanol
Biogas
Biodiesel
Bio-Oil
Fuel Gas</td></tr>
<tr><td>Micro Turbine</td><td>External</td><td>25-250</td><td>85-100</td><td>Biogas
Biodiesel
Fuel Gas
Heat</td></tr>
<tr><td>Stirling Engine</td><td>External</td><td>10-150</td><td>60-80</td><td rowspan="2">Direct Biomass Combustion</td></tr>
<tr><td>Organic Rankine Cycle Turbine</td><td>External</td><td>200-1,500</td><td>80-100</td></tr>
<tr><td>Steam Engine</td><td>External</td><td>20-10,000</td><td>85-120</td><td>Biogas
Bio-Oil
Fuel Gas
Heat</td></tr>
</table>

Table 7-2: Small-Scale Power Generation Technology, adapted from (Lensu & Alakangas, 2004, pp. 27, 43-49).

7.2 Large-Scale Biofuel Production Industry

Author: Y.Q. Yao & M.A. Haji Md. Said

As world oil resources are shrinking, oil prices continue to increase and this is verified by the fact that the annual oil prices rose for a 7th consecutive year in 2008, which is a record first in the nearly 150-year history of the oil industry (50). However in 2009, the oil prices recorded a 37% (to that of 2008) decline, which in fact is the largest decline since 1986 (39). Due to the growing energy demand, local companies and governments alike began to focus on the production of biofuels with the aim of saving local resources, reducing pollutions and increase sustainability. Despite still facing various constraints in terms of technology development and cost aspects, biofuel production is still deemed to have a great potential (and advantages) as the foreseeable future substitute of fossil fuels.

Analysing the industry, there are quite a number of companies venturing into the research and development of technologies on the production biofuel from the organic waste, which includes Achor International, Abengoa Bioenergy, Enerkem, BP, and St1. As discussed in *"History of Biofuel Production'* section, biofuel is becoming more and more famous as an alternative source of energy, for reasons that can be accounted to the increased pressure on the current world's petroleum resource. This is especially the case when the world's petroleum reserves are estimated only to last for another 46 years (i.e. based on the *'reserves-to-production'* analysis by BP) [39] as well as the rapid development of the world's Transportation Industry (especially in the developing countries such as China and India).

This chapter will therefore look into (and discuss) the different organizations and companies that run projects revolving around the production of biofuel.

7.2.1 Achor International

As mentioned in the introduction to this report, due to the fact that this project is run in collaboration with Achor International, the group thought that it would be a good idea to do a little research in order to understand the organisation and the level of technologies that Achor have been researching and developing. Based in East Anglia, Achor is an international scientific research, technology development and commercialisation company with operations in the USA as well as India (Achor International Ltd., 2009). Their current focus is the deployment of their patented process for the conversion of Municipal Solid Waste to fuel alcohols (Achor International Ltd., 2009).

Achor, through their website (Achor International Ltd., 2009), presented some positive facts of the current technology that they have successfully developed to convert solid waste to fuel alcohols using cutting-edge microbial science and systems engineering, where the advantages of the technology includes the following:

1. Yields 300 litres of fuel alcohol per tonne of paper, card, or vegetable waste;
2. Reduces the total volume of mixed municipal solid waste going to landfill by 60%;
3. Pays for itself in less than half the time of an equivalent volume anaerobic digestion facility.

It is the aim of the group that a constant contact and exchange of information between the group and Achor will be sustained throughout the life cycle of this project. This is especially the case for when the group require advice on any of the processes involved, be it in the production of the biofuel or manufacturing and improving the prototype.

7.2.2 Abengoa Bioenergy

Abengoa Bioenergy is a global ethanol company based in Spain, with aims dedicated to the production and development of bio-fuels for transport consumption such as bio-ethanol and bio-diesel. The company is the largest bio-fuel producer in Europe and one of the largest in the USA and Brazil, with a total annual production capacity of around 2.5 billion litres in countries that spans throughout three continents, which includes Brazil, France, Germany, UK, USA, and Spain (Abengoa Bioenergy).

The company (since their establishment) have dedicatedly contributed to greenhouse gas reduction programme. In fact they have achieved a reduction of an equivalent to approximately 1.82 million tonnes of CO_2 emissions with the commercialization of over 1.5 billion litres of bio-ethanol in 2009, which is equivalent to the annual emissions from approximately 0.5 million vehicles (Abengoa Bioenergy).

Taking a closer look into the technology that Abengoa Bioenergy utilises in the production of bio-ethanol (which is of great significance to this project) from cereal-type crops as the feedstock, the processes that the feedstock are exposed to is rather similar to that chain of processes involved in this project i.e. enzymatic hydrolysis, bacterial fermentation and distillation (as per discussed in the *'Review of Bio-Chemical Processes'* section). Currently, the use of bio-ethanol as the fuel for the Transportation Industry is limited to the engines that have been adapted to run on an ethanol-petrol blend of up to 85%. This however does present a positive incentive towards a more sustainable option of fuel as compared to using pure petrol and/or gasoline. Below are further advantages of using bio-ethanol as fuel compared to its counterpart derived from fossil fuels i.e. as listed in the annual report published by Abengoa Bioenergy (Abengoa Bioenergy):

1. Renewable origin;
2. Biodegradable, which means that they can be broken down easily;
3. Its use contributes to diversification of the autonomy of the source of energy that tackles the high dependency on oil imports;
4. Cleaner fuel which significantly reduces the emissions of pollutants such as sulphur oxide;
5. Reduction of greenhouse gas (GHG) emissions, which is a key player in the Climate Change debate where it is blamed as a contributory factor to the rising world temperatures;
6. Lastly, they are easy to obtain and store.

One of the other major products that Abengoa Bioenergy produces include bio-diesel, which is produced through the chemical reaction of methanol with vegetable oils such as sunflower, soy, and palm oils, a reaction that produces long-chain fatty acid, methyl- or ethyl-esters (Abengoa Bioenergy). In addition to being one of the renewable fuels currently available in the market today, biodiesel also does not contain sulphur; hence the usage of biodiesel would reduce GHG emissions as well as the emissions of any other pollutants when compared to its counterpart that is sourced from fossil fuels. In addition to this, Abengoa Bioenergy also produces other products such as Distillers Grains Soluble (DGS), Sugar, and Electricity as well as CO_2 that is supplied to gas companies. The group would duly advise readers to refer to the report published on Abengoa Bioenergy website titled *'Abengoa Bioenergy 2009 Annual Report'*, for further (and detailed) information on the other products that Abengoa Bioenergy supplies due to the fact that these products are not directly related to the aims of this project.

7.2.3 Enerkem

Enerkem (on the other hand) is one of the leading chemical companies based in Canada who are involved in the research and development of the systems that convert waste into biofuels. Their technology focuses mainly on processing residual materials such as non-recyclable municipal solid waste, where it is converted into usable products such as transportation fuels and green electricity (Enerkem). As published in their website, Enerkem's plants offer environmental and energy benefits to communities (Enerkem) as listed in Table 7-3.

Environmental Benefits	Energy Benefits
The need for landfilling municipal solid waste is dramatically reduced. As the result, emissions of methane, which is 25 times more potent than carbon dioxide as a greenhouse gas, created from the decomposition of the waste at landfills are also avoided effectively.	Energy security and independence are feasible by producing fuel locally and by reducing imports.
Each plant helps reduce greenhouse gas emissions by more than 240,000 dry tonnes annually, which is the equivalent of taking more than 42,000 cars off the road per year.	Advanced biofuels produced by Enerkem contribute to Renewable Fuel Standards, which require the blending of renewable fuels in gasoline. Each plant produces at least 36 million litres or 10 million gallons of clean fuels or advanced chemicals annually.
The production process meets high air emission standards, is energy efficient and minimizes water consumption by using it in a closed circuit.	

Table 7-3: Environmental & Energy benefits of Enerkem's Plants, sourced from (Enerkem).

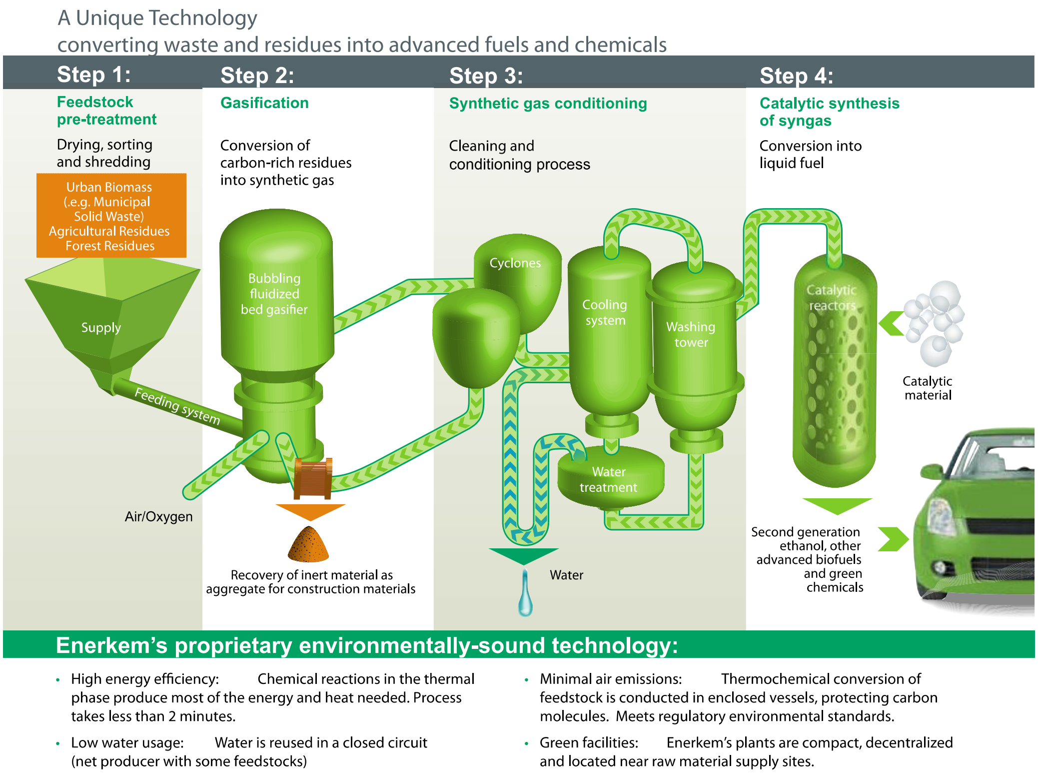


Figure 7.1: Enerkem's Biofiel Production Technology Sourced from (Enerkem).

Enerkem (in the design of their production technology) utilises a 4-step process to produce bio-ethanol from waste as the feedstock (Figure 7.1), this is described in their website as follows (Enerkem):

"Step 1 – Feedstock pre-treatment: The urban biomass, forest residues and agricultural residues are shredded, sorted and dried then stored in a container which is connected with the gasifer. Step 2 – Gasification: This process is to convert carbon-rich residues into synthetic gas, which is extracted (using fan) into the next section where the gas will undergo several treatments. Step 3 – Cleaning and conditioning of synthetic gas: The gas is cleaned, conditioned and treated according to Enerkem's production standard in preparation for the gas to be converted into liquid fuel using known catalysts. Step 4 – Conversion into liquid fuel: When the clean and conditioned gas enters the catalytic reactors, the catalytic material starts converting the synthetic gas into liquid fuel and eventually market-ready fuels and other chemicals."

Currently, most of Enerkem's bio-ethanol is produced in their Westbury plant, located in Quebec, Canada. The plant has a considerable capacity of producing 5 million litres (1.3 million gallons) per annum of second-generation (2G) biofuel.

7.2.4 BP

BP is one of the world's largest energy companies that incorporates the research, development, and production of sustainable biofuel as its mission and aim (which is an alternative fuel that is considered to be cleaner and more reliable) in order to sustain the demand in the supply of fuel for transportation and alleviate the demand on fuels that is derived from fossil fuels. BP currently contributes to 10% of the world's ethanol market and in 2008 BP blended and marketed over 3.8 billion litres (1 billion gallon) of ethanol in the US alone. Currently BP has several projects that are related to the production of biofuel around the world, which include a technology demonstration plant located in the UK, BioEnergia SA in Brazil and Vercipia Biofuels in the US (BP).

7.2.4.1 Technology Demonstration Plant

The technology demonstration plant was built in collaboration between BP and DuPoint to demonstrate a cost-effective way of producing bio-butanol. Bio-butanol is an advanced biofuel with higher energy content than ethanol, which can be produced using sugarcane, wheat, or corn (i.e. a selection of feedstock which are renewable). Furthermore, bio-butanol can also be blended with gasoline at a higher percentage compared to ethanol and it can also be used in existing vehicles without any need for engine modifications.

As discussed in the previous chapters, since the project began two years ago, the production of bio-butanol (as the end product) has been considered. However due to a limited knowledge of the operating conditions on the production of bio-butanol, an anticipated complication in collecting the final product, and more importantly the constraints in the allocated project budget a final decision was duly made against the production of bio-butanol.

7.2.4.2 BioEnergia SA

As of 2008, BP has owned a 50% share of the joint venture project called Tropical BioEnergia SA (BP). This is a project that was first established by Louis Dreyfus Commodities-Santelisa Vale (LDC-SEV) with Maeda Group (BP). The project produces bio-ethanol with sugarcane (a lignocellulose biomass) as a feedstock, and the current refinery has an operating capacity of producing 0.4 billion litres of ethanol in Brazil annually. BP's total investment in the joint venture will be pumped up to US$1 billion with the second refinery due to be built (BP) and when the two refineries are in full operation, the project will be able to produce enough ethanol from locally grown sugarcane to support the Brazilian domestic fuel demand and potentially even export to the US, Europe and Asia. In addition to that, with the integration of bagasse (i.e. post-processing residue of sugarcane) co-generation facility, the two refineries will be able to sell surplus electricity generated to the state grid and each of the refineries is expected to be able to export at least 30 Mega Watts of power. BP also claims that (currently) sugarcane is the most efficient feedstock to produce biofuel for commercial purposes and ethanol that is produced from sugarcane can generate up to 90% reduction of greenhouse gas (GHG) emission compared to fossil fuels (BP).

7.2.4.3 Vercipia Biofuels

In addition to that, BP also acquired Verenium Corporation's US$98.3 million biofuel lignocellulose assets to become the sole owner of Vercipia Biofuels, which is based in Tampa, Florida (BP). Vercipia Biofuels is currently finalising its design to develop a commercial-scale cellulosic-based ethanol producing facilities in the US. The facility is estimated to cost around US$250-300 million to construct and the construction is expected to start in 2011 with production expected to commence in 2013 (BP).

7.2.4.4 Other BP Projects and Investments

BP is also investing US$500 million over a 10-year period to support the Energy Biosciences Institute in its research and investigations on the applications of biotechnology including advanced biofuels (BP). In 2009, BP announced a joint agreement with Martek Biosciences Corporation to make a progress on the development of the technologies to convert sugars into bio-diesel. They believe sugar-to-diesel technology has its potential to deliver economically sound and sustainable bio-diesel supplies and BP plans to roll the technology out onto the mass market within 5 years. In addition to that, BP is also involved in several other projects with the focus on researching and developing energy crops, which they believe to have the potential to be utilised as the feedstock for the production of the next generation biofuel (BP). BP (in their website) published the benefits of producing biofuels using the dedicated energy crops; a summary of which is as follows:

1. They contain a lot of sugar that can be turned into energy using BP's advanced biomass conversion technology;
2. They produce higher volumes of fuel per ton of feedstock and per 10,000 m2 (2.5 Acres) of agricultural field compared with current biofuels – i.e. up to 3 times more than corn and agricultural wastes;
3. They can be grown on less productive land and closer to production facilities – delivering an improved logistics, lowering costs, and reducing environmental and agricultural impacts;
4. As crops many of them efficiently recycle nutrients and can take carbon from the air and fix it into the soil, which helps to improve its quality over time.

7.2.5 St1

St1 is a Finnish energy company whose business includes the research and development of economically viable and environmentally sustainable energy solutions. The business model of the company mainly focuses on fuel distribution aspect as well as the supply of CO_2-aware energy products and services, an example of which includes a high-blend bio-ethanol fuel generated from waste. Their distribution-site network is one of the largest in Finland consisting of 160 service stations, 200 unmanned sites and 30 truck-stations as well as owning over 30 sites dedicated for marine vehicles across Finland as well as in their neighbouring nations of Norway, Poland and Sweden (St1). St1's CO_2-aware energy products and services include high-blends of bio-ethanol fuels (which are produced from bio-waste and side-streams from local food industry) a product that is closely related to this project. Their ethanol production plants are built next to sources of feedstock such as bakeries and breweries.

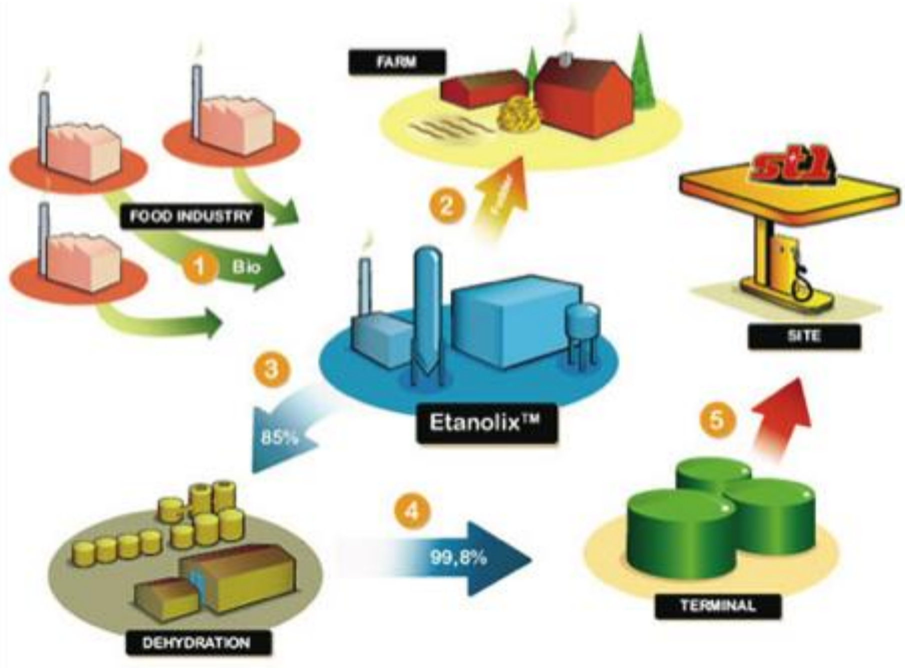


Figure 7.2: St1's Waste-to-Ethanol Concept, source (St1).

Figure 7.2 shows a brief description of St1's operation model for the production of ethanol, and from their website (St1) the model were described as follows:

> *"(1) Small bio-ethanol production units are built near to the source of fermentable feed stock to minimise transportation need. (2) By-products from the process (e.g. fertilizers, animal feed or solid bio-fuel) are used locally. (3) From the small production units, the product (which is an 85% concentration of bio-ethanol) is shipped to a separate dehydration unit for dewatering. (4) After the dewatering, the concentration of bio-ethanol is enhanced to 99.8% and is then transferred to a storage plant ready to be blended with gasoline prior to being distributed to their service stations in different locations."*

Concept Plants	Descriptions
Bionolix	The Bionolix plant is the second-generation plant in Waste-to-Ethanol concept and it uses municipal and commercial bio-waste as feedstock. The production processes of Bionolix includes pre-handling, fermenting and drying of bio-waste and its by-product can be used as energy in the process or as a compost material.
Cellunolix	These new plant types will bring new feedstock and new technology into ethanol production. Municipal biowaste, packaging waste from households, industry and stores will become the new feedstock for producing bioethanol.
Dehydration Plant	St1's dehydration plants, which dewater the ethanol, produced in the small-dispersed units and its annual capacity is 88,000 m3 of 99.8% ethanol.
Ethanolix	It is the first plant type in St1's Waste-to-Ethanol concept and it uses food industry side steams as feedstock. This concept has its modular design (easy and fast installation), functions on subsequent fermentation and ethanol take off. It consumes renewable energy and its by-products are produced with equivalent energy. Each Etanolix plant (ethanol production plant) has its ability to produce an average of 1000 m3 per year and the area needed for unit is only approximate 25m×25m and they are unmanned and controlled by remote operation.
Fiberix	Fiberix is based on cellulosic technology that use agricultural residue e.g. straw.

Table 7-4: Summary of St1's Concept Plants, adapted from (St1).

Table 7-4 presents a summary of St1's current Concept Plants which were designed to utilise biological or organic waste streams as the feedstock to produce useful second generation (2G) biofuels.

7.2.6 Expanding Domestic Biofuel Production in Japan

Japan is one of the many nations that have embraced the production of biofuel with the Japanese Government setting a goal to produce 50 million litres of domestic biofuel by 2011 and 6 billion litres by 2030 (Asia Biomass Energy Cooperation Promotion Office). In order to achieve these goals, the Japanese governments has proposed utilising such raw materials (i.e. feedstock) as listed in the next page, for the production of the biofuel.

List of proposed feedstock and raw materials for Japanese biofuel production:

- Agricultural by-products such as rice and wheat straw;
- Energy crops that are left behind on abandoned farmlands, such as rice and beets;
- Ligneous biomass such as woody construction waste and forest residue.

At present, Japan claims to have a Self-Energy ratio of 38%, which includes an 18% self-sufficiency of energy supply as well as a 20% resource interest in foreign countries that are owned by the Japanese Government and various Japanese companies (Asia Biomass Energy Cooperation Promotion Office). On 28 April 2010, the Japanese Ministry of Economy, Trade, and Industry announced that Japan is targeting to raise this ratio to 70% by 2030 (Asia Biomass Energy Cooperation Promotion Office). The Ministry reckons that the expansion of their domestic biofuel production is deemed to be one of the effective ways of achieving the goal. This therefore encouraged local Japanese universities and institutes as well as private companies to embrace and promote research and developments in the field of biofuel production technology to support this program. Table 7-5 lists a summary of some of the Japanese organisations that are dedicated to support this program.

Institutes / Companies	Developments / Production of Domestic Biofuel
Nippon Steel Engineering Corp.	Announced the completion of an experiment of bio-ethanol production from food waste on 19th April 2010. Collected around 10 ton/day of food waste (that are separated from other wastes) in Kitakyushu City and produces around 500 litres of bioethanol per day. They also carried out experimental runs on E3 gasoline (i.e. 3% bioethanol mixture gasoline).
AIST (Advance Industrial Science and Technology) i.e. part of Sugino Machine, Ltd.	On 13th April 2010, they announced the development of 'Crush/Miniaturization Technology' of cellulose by utilising water jets. In addition to that, they also announced that they have increased the efficiency of the conversion of cellulose to glucose (using enzyme based hydrolysis) by six folds.
Asahi Breweries, Ltd. & National Agricultural Research Centre for Kyushu Okinawa Region	Announced, on 13th April 2010, the development of low-cost, large-scale bioethanol production with the utilisation of high-quality biomass sugarcane (classed as 'KY01-2044'), which has a 1.5 times production yield as well as 1.3 times sugar yield compared to its predecessors.
Nippon Oil Corp, Hitachi Plant Technologies, Ltd. & Euglena Co., Ltd.	On 8th March 2010, announced the cultivation of Euglena (a 0.1 mm length plankton) in ponds and swimming pools, which has high productivity rate. The oil contained in the planktons will be extracted and processed for use as fuels for aeroplanes, such oil will cost around ¥70 per litre.

Table 7-5: Summary of Research & Developments of Japanese Domestic Biofuel Production, adapted from a report by Asia Biomass Energy Cooperation Promotion Office (Asia Biomass Energy Cooperation Promotion Office).

8 Analysis of the Inherited Prototype

Authors: A. Jarušauskas, M.A. Haji Md. Said, C. Obi, & Y.Q. Yao

This chapter will focus the discussion on analysing the prototype that the group have inherited from the previous group to have undertaken the project i.e. Laxman et al (Team 09/10). The chapter is divided into two main sections, the first of which will highlight any of the problems or shortcomings of the built prototype. The second section will look into the heat transfer analysis and energy balance of the built prototype, which is done in order to determine the efficiency of the current prototype as well as to produce a benchmark with which the group can weigh any improvements made.

8.1 Highlight of the Problems of the Existing Prototype

Before the project can be considered a success, it is important to ensure that the final design of the production system is commercially viable. This section therefore highlights the shortcomings of the current prototype with some suggestions on the proposed plans of action in order to improve them. The section is divided into three main parts, the first of which will focus on the analysis of the current electrical and control system design. The second part will focus on the analysis of the mechanical system design and the last will focus on analysing the bio-chemical process design of the built prototype.

8.1.1 Electrical and Control System

Author: A. Jarušauskas

8.1.1.1 Automation

A high level of automation is a desirable feature for this kind of project. The previous groups to undertake the project have attempted to design a control system to enable the prototype to work on its own accord, but the results were not as good as expected. At present, it is rather difficult to firmly say what level of automation is achievable, and a complete level of automation would require a purpose-built and designed rig with tightly executed electro-mechanical integration. Time and budget constraints however mean that this cannot be achieved within the period of a year, which inevitably is the time frame that this project has been subscribed. Hence, the team expects (at the very least) to complete the implementation of features that were started by the previous groups such as the pH control and balance system.

8.1.1.2 Redesign of Heating System

One of the main problems faced by Team 09/10 was the failure of one of the heating elements, reasons for which were clearly stated in their final report titled *'Small Scale Biofuel Production'* (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010):

> *"The boil-dry cut-out switch that was wired onto the bottom of the element kept tripping, and after attempting at multiple stages to bypass, or force the switch on, which worked for most of the tests, the element eventually stopped working altogether."*

Therefore, it is necessary to find a more robust heating element and incorporate it into the existing prototype. In addition to that, a more sophisticated control of power (applied to the element) is planned as a replacement for previously implemented ON-OFF control system.

8.1.1.3 Redesign of Hardware and Firmware

Another problem with the inherited control system is that it is not reusable or maintainable. While breadboard and flying wires may be acceptable during early stages of prototyping, a printed circuit board (PCB) is a much better solution.

On the firmware side, a work will have to be done to replace the current assembly code with a more maintainable C code. This would allow future groups who choose to undertake the project to continue improving the firmware rather than rewriting everything from scratch. Therefore, a good documentation should also be created alongside the code.

Last but not least, the group plans to reduce the overall cost of the electrical and control systems by taking a different design approach and appropriate selection of components.

8.1.2 Mechanical System

Author: M.A. Haji Md. Said & Y.Q. Yao

8.1.2.1 Reconsideration of the Reflux Still Design

Upon analysing the report written by Laxman et al (Team 09/10), and perhaps in line with their recommendation, the group reckons that there is a margin for improvement to the design of the implemented distillation system. The group sense a flaw in the current design of the Reflux Still and believe that the prototype would benefit from a revision of the design, especially on how the steam is fed into the cooling chamber as well as that of the cooling water.

In addition to that, the group is also in agreement that the project will benefit from research into the determination and quantification of the amount of heat lost via the Reflux Still (also as per recommendations listed by Team 09/10), especially due to the fact that the Reflux Still was fabricated completely from copper. This is because a significant heat loss may potentially have a detrimental effect on the temperature monitoring system within the system itself. Hence if this could be determined (and confirmed), the group reckons that a re-fabrication of a similar design of the Reflux Still using materials with lower conductivity would be the next logical step in order to improve the system.

8.1.2.2 Filtration System and Impeller Design

Team 09/10 in their final report also expressed the fact that the slurry was quite dense and chunky, which causes problems to the pump system they have implemented onto the prototype, rendering it useless. Therefore, the group suggests that it is a good idea to research into the potential of implementing some sort of filtration system onto the prototype to avoid any problems in terms of transferring the slurry from one chamber to the other.

In addition to that, the inherited prototype utilised a down-pumping impeller design to agitate the slurry during the hydrolysis and fermentation processes. The group reckons that this design, coupled with the fact that the slurry is quite dense and chunky, have contributed to the failure in the heating elements. Hence, the group thought it would be beneficial to revise the design of impeller to agitate the slurry.

8.1.2.3 Maximising Space Usage and Utilising 'Free' Energy

The group acknowledges the fact that Team 09/10 did manage to reduce the size of the prototype. Whereas in the original prototype, all the three main processes are carried on in three separate vessels, the improved prototype only utilises two vessels, where the hydrolysis and fermentation processes are combined into one vessel, whilst the other vessel was used solely as the distillation chamber. The group reckons that perhaps it would be possible to further reduce the floor-space occupied by the current prototype by either combining all the three main processes into one vessel or failing that it would perhaps be best to stack the vessels on top of one another.

In addition to that, acknowledging the fact that the project is now run in a premise with a good supply of water, the group thought it would be beneficial to utilise this fact and incorporate it to the overall design of the prototype. The group thought that it would be advantageous especially when the fact is coupled with the suggestion to stack the vessels on top of one another, where the power of gravity will come into play in moving matters (such as mobilising the cooling water system or migrating the slurry from one vessel to another) around the system. This would undoubtedly have a reduction effect on the overall power consumption of the whole system, which consequently means that there is a potential of increasing the efficiency of the system. Lastly, perhaps it would also be beneficial to consider implementation of some form of insulation to the system in the bid to reduce the amount of heat loss, and increase the overall efficiency.

8.1.3 Bio-Chemical Optimisation

Author: C Obi

Research into alternative methods of pre-treatment (e.g. sterilisation and gelatinisation) to ensure optimum conversion of sugar into alcohol (ethanol) will be done during the course of carrying out this project. The pre-treatment procedure used by the previous groups involved the use of a macerator (InSinkErator) to prepare the potatoes with a measured quantity of water (i.e. in a ratio of 1:1). Despite the fact that this method has been proven to be fairly efficient, the group nevertheless thought that it would be of benefit to the project to do research into an additional (or alternative) method of pre-treating the feedstock that could improve the efficiency of the production. This is due to the fact that an effective pre-treatment process could lead to the increase in the effectiveness of the hydrolysis and fermentation process to turn the starch-rich potatoes into alcohol.

The group, based on the research done by Awolokun et al (Team 08/09) (Awolokun, Adams, Hambos, & Parr, 2009) and Laxman et al (Team 09/10) (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010), acknowledges the fact that yeasts cannot survive at temperatures in excess of 30°C. Therefore, research into a quicker method of cooling the slurry as well as the possibility of utilising the heat elsewhere would be valuable. In addition to that, the group also thought that it would be of benefit to the project if research were to be done on the availability of suitable enzymes with optimum working temperatures lower than the current temperature of 50°C. This would definitely help reduce the amount of time taken to cool the temperature of the slurry down after the hydrolysis process in order to start the fermentation process. Hence, this would consequently result in a possible reduction of the overall time taken for the production of ethanol in this project, which does technically improve the efficiency of the prototype.

Team 09/10 also suggested (as part of their recommended future work) an investigation towards discovering the optimum length of time the fermentation process can be allowed to run to achieve the best alcohol yield (i.e. a high concentration of yield per unit weight of feedstock used). Based on their experimental run of the fermentation process, where they allowed the fermentation process to run close to 72 hours (i.e. 3 days), they concluded that the longer the slurry is fermented the higher the alcohol yield is. Therefore, the group thought it would be of crucial importance for the future success of this project to run an experiment to determine a precise optimal length of time to run the fermentation process that gives the greatest alcohol yield.

8.2 Theoretical Heat Transfer Analyses

Author: Y.Q. Yao & M.A. Haji Md. Said

This section (as the title suggests) will present the theoretical heat transfer analyses on the current prototype. The main aim of the analyses is to determine the amount of heat energy lost during the processes of hydrolysis, fermentation, and distillation. The section is divided into two main parts, the first of which will focus on analysing the heat transfer profile of the containment vessels. The second part will then focus on the study of the heat transfer profile of the Reflux Still i.e. the heat lost through the copper pipes used to build the Reflux Still.

8.2.1 Containment Vessel Analysis

The prototype that the group inherited from Team 09/10 utilises two main vessels for the three processes of converting the starch-rich potatoes into bio-ethanol. The first of which is used for both the hydrolysis and fermentation processes whilst the remaining vessel is used solely as the distillation chamber. Team 09/10, in their improvement to the prototype they inherited from Team 08/09, implemented a domestic tea-urn (illustrated in Figure 8.1) used mainly in the catering business, for reasons which are clearly stated in their report.

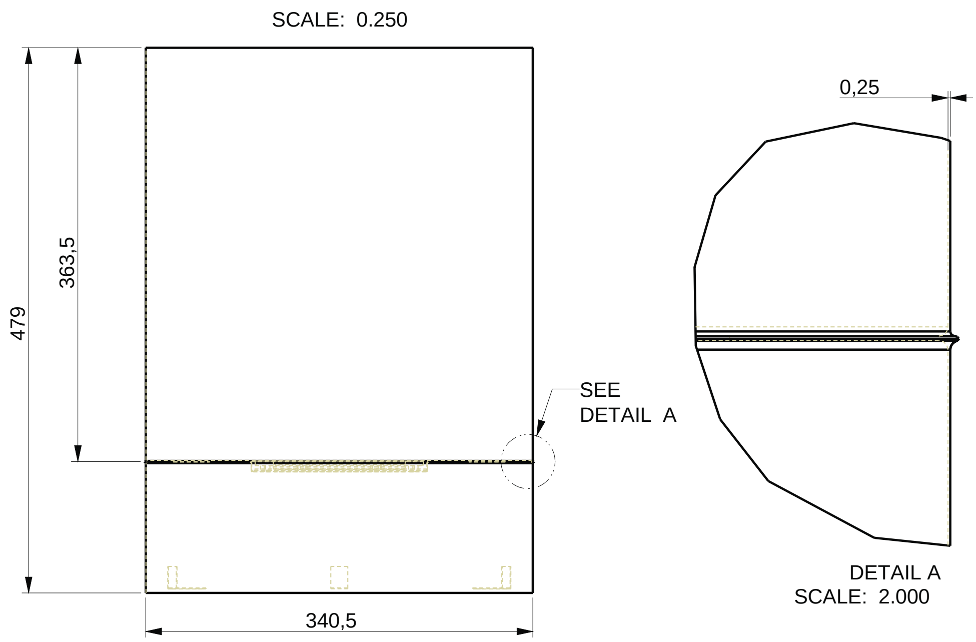


Figure 8.1: Technical Drawing of the Tea-urn (all dimensions are in mm).

The calculations that were done in this section will be based on a steady-state condition, where the surrounding air (i.e. room) temperature, T_∞, is assumed to be 15°C and the internal temperatures of the vessels are assumed to be evenly distributed at the optimum temperatures of the respective processes i.e. 50°C, 30°C, and 78°C respectively for the processes of hydrolysis, fermentation, and distillation. The calculations will also be utilising such material properties as presented in Table 8-1, details of which were adapted from the appendices of the *Fundamentals of Heat and Mass Transfer* book written by Incopera et al (Incopera, Dewitt, Bergman, & Lavine, 2007).

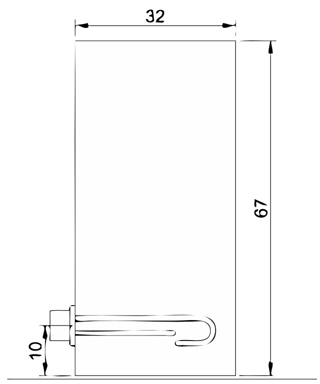


Figure 8.2: Illustration of the Inherited Distillation Chamber.

Materials		Thermophysical Properties			
		Density, ρ (kg/m^3)	Thermal Conductivity, k (W/m·K)	Specific Heat Capacity, c_p (J/kg·K)	Viscosity, $\mu \cdot 10^7$ ($N{\cdot}s/m^2$)
Aluminium Alloy (2024-T6)		2,770	177	875	-
Stainless Steel (AISI 302)		8,055	15.1	480	-
Commercial Bronze (Copper)		8,800	52	480	-
Air (at 15°C)		1.2174	25.34	1.0067	178.6
Steam (at 78°C)[1]		0.0972	22.74	1.946	11.22
Water	At 30°C	1,000	620	4.178×10^{-3}	7690
	At 50°C		645	4.182×10^{-3}	5280
	At 78°C		670	4.197×10^{-3}	3738

Table 8-1: Thermophysical Properties of Materials, adapted from (Incopera, Dewitt, Bergman, & Lavine, 2007).

[1] Sourced from (Rogers & Mayhew, 1995)

As mentioned previously, the first of the two vessels is used mainly for the hydrolysis and fermentation processes. Based on the experimental run carried out by Team 09/10, the temperature of the potato slurry was maintained at 50°C for the duration of three hours during the hydrolysis process, whereas for the fermentation process the temperature was kept at 30°C for 24 hours. Once the fermentation process is done the slurry was transferred to the distillation chamber (which was constructed from Stainless Steel and is illustrated in Figure 8.2) and the distillation process was run for a period of 40 minutes. Due to the fact that a high percentage of the potato slurry is constituted by water content, the group decided that (for the simplicity in the calculation methods) the thermophysical property of the slurry is equated to that of water at the specified temperatures. In addition to that, the internal and external surface temperatures of the vessel wall are assumed to be equal to each other due to the fact that the vessel wall is significantly thin (i.e. 0.25 mm).

Hence (based on this information), the heat transfer analysis of the containment vessels could therefore be calculated using relevant heat transfer theory. The basic heat transfer theory utilised in this section is the thermal conduction and convection rate equations based on Fourier's Law (i.e. heat flux, q), which for the analyses of the vessels can be illustrated using the equation as follows:

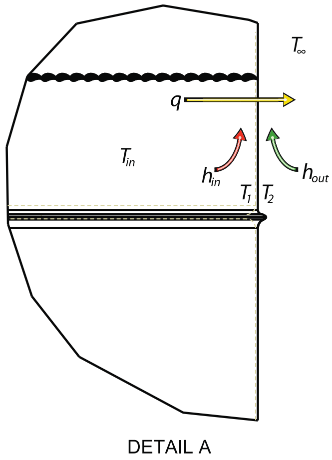


Figure 8.3: Heat Transfer Coefficient Illustration.

$$q = \frac{T_{in} - T_{\infty}}{\left(\frac{1}{h_{in}} + \frac{L}{k} + \frac{1}{h_{out}}\right)} \qquad (8.1)$$

As illustrated in Figure 8.3, h_{in} and h_{out} are the heat transfer coefficients of the fluid on the inside and outside environment of the vessel. L is the thickness of vessel wall and k is the thermal conductivity of vessel, which is made of Aluminium alloy.

However, in order to evaluate the heat transfer coefficients a second theory (relating to free convection analysis as explained by Long in his book titled *'Essential Heat Transfer'* (Long, 1999)) would be required which can be illustrated as follows:

$$Nu_{av} = 0.516(GrPr)^{\frac{1}{4}} \qquad (8.2)$$

By expanding each of the terms in equation 8.2 (as illustrated in equation 8.3) and substituting the appropriate details into the expanded equation the internal and external heat transfer coefficients can then be determined.

$$\left(\frac{h_x L}{k}\right)_{av} = 0.516\left[\left(\frac{\rho^2 g \beta \Delta T L^3}{\mu^2}\right)\left(\frac{\mu C_p}{k}\right)\right]_{fluid}^{\frac{1}{4}} \qquad (8.3)$$

While *'x'* denotes either internal (*'in'*) or external (*'out'*) heat transfer coefficient, the term *'fluid'* means that the properties represented in the equation denotes that of the fluid which is adjacent to the wall surface respective of *'x'*. ΔT however, denotes the temperature difference between the wall surface and its adjacent fluid environment, g represents the acceleration due to gravitational pull i.e. 9.81 $m \cdot s^{-2}$, whereas β is the fluid buoyancy term which (for steady-state condition) can be equated to T_{fluid}^{-1}.

Substituting all the parameters presented in Table 8-1, taking into account all the assumptions discussed in the previous paragraphs, the heat transfer coefficients of the three main processes (hydrolysis, fermentation, and distillation) can be summarised as follows:

Heat Transfer Coefficients $(kW/m^2{\cdot}K)$	Processes		
	Hydrolysis	Fermentation	Distillation
h_{in}	9.84	7.43	12.13
h_{out}	7.08	5.82	8.08

Table 8-2: Summary of Heat Transfer Coefficients for the Three Processes.

The heat flux can therefore be determined from equation 8.1 using the calculated values of heat transfer coefficients presented in Table 8-2 as well as all related parameters from Table 8-1. Once the heat flux is determined, the amount of heat loss, Q, and total energy loss, E, can then be calculated using equations 8.4 and 8.5 respectively where A is the surface area of the vessel and t is total time taken for the processes. The values of the heat flux as well as the amount of heat loss through the three processes are summarised in Table 8-3.

$$Q = q \cdot A \qquad (8.4)$$

$$E = Q \cdot t \qquad (8.5)$$

Particulars	Processes		
	Hydrolysis	Fermentation	Distillation
Heat Flux, q ($\mathrm{kW/m^2}$)	74.3	29.8	13.7
Heat Loss, Q (kW)	28.9	11.6	92.3
Energy Loss (MJ)	312	1,000	222

Table 8-3: Summary of Heat Flux and Heat Loss Values for the Three Processes.

8.2.2 Distillation Process (Pipe) Analysis

A similar set of theories could also be applied to the heat transfer analysis of the Reflux Still. However, due to the complicated design of the Reflux Still (Figure 8.4), the group assumed it to be a straight pipe in order to simplify the calculations. The length of the pipe is taken to be the distance travelled between the points at which the ethanol vapour enters the Reflux Still to that when it enters the cooling chamber, which the group estimated to be 939 mm.

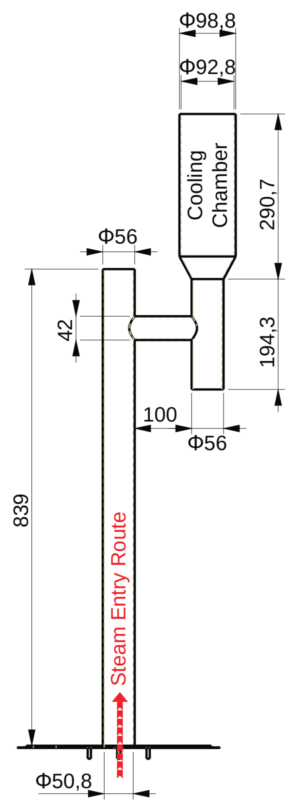


Figure 8.4: Technical Drawing of the Reflux Still (all dimensions are in mm).

Similar to the assumptions made for the calculations in the previous section, the ambient (air) temperature, T_∞, is assumed to be 15°C and the temperature inside the Reflux Still is assumed to be the temperature at which ethanol evaporates i.e. 78°C. For the purpose of simplifying the calculations, the fluid properties inside the Reflux Still is equated to that of steam at 78°C. Hence, using equations 8.1, 8.3, and 8.4 (taking L as the thickness of the pipe) as well as the thermophysical properties of copper and steam presented in Table 8-1, the heat transfer coefficients can be found which consequently means that the heat flux and the heat loss can also be determined; this is summarised in Table 8-4.

Reflux Still Parameters				
Heat Transfer Coefficient $(\mathrm{kW/m^2{\cdot}K})$		**Heat Flux** $q \cdot 10^{-3}$ $(\mathrm{W/m^2})$	**Heat Loss** Q (kW)	**Energy Loss** E (kJ)
h_{in}	h_{out}			
0.28	0.83	4.77	0.79	1.89

Table 8-4: Heat Transfer Analysis Parameters for the Reflux Still

In acknowledgement of the high thermal conductivity of copper, the group did consider the use of PVC or thermoplastic pipes instead of copper to build the Reflux Still with, mainly due to its insulating property. Theoretically, replacing the copper pipe with thermoplastic materials that have much lower thermal conductivity, the heat loss can be dramatically reduced. Hence, some research was done to survey the availability of suitable thermoplastic pipes as well as the cost of acquiring them. However, the group were advised by an advisor from a local (Brighton) plumbing supply company that for the application of this project the best thermoplastic pipe to use is the MuPVC pipes, although a metre of copper pipe would still necessarily be used between the boiler and the thermoplastic pipes to avoid damaging and deforming the thermoplastic pipes. In addition to that, due to the speciality of the project's application, the group may well need to make a customised-order, which would definitely be stretching the group's budget. As this is the case, the benefits of using thermoplastic pipes to build the

Reflux Still cannot be justified due to the potential high cost of acquiring thermoplastic pipes, the group therefore aims to modify the current design of the Reflux Still and perhaps apply some external insulation to the pipes to reduce unnecessary heat loss.

8.2.3 Energy Balance of the System

Based on the analysis done by Laxman et al (Team 09/10), energy consumption of the four main processes involved in converting potatoes into ethanol are summarised in Table 8-5. Due to the fact that the group have no intention of utilising the heating belt used by Team 09/10 to maintain the temperatures of the slurry throughout the processes of hydrolysis and fermentation nor does the group intend to use the pump system, in the summarised energy consumption presented in Table 8-5, the group decided to discard any calculations towards the energy consumption of the heating belt and the pump.

Energy Consumption, (kJ)			
Pre-Treatment	**Hydrolysis**	**Fermentation**	**Distillation**
220	901	9.76	4,800

Table 8-5: Summary of Energy Consumption of the Different Processes, adapted from (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010).

Therefore, combining this information to the calculations of heat loss through the different processes (presented in the previous sections), the total energy input to the system is found to be in excess of 1 GJ, which is a colossal amount of energy. Team 09/10 pointed out that the distillation process significantly contributed to this value due to its large energy consumption, what the group have now found from this heat transfer analysis is that the greatest amount of heat loss (which consequently significantly spiked the value of energy input to the system) is during the fermentation process.

In conclusion, the group considered that this is a significant weak-point of the current prototype that needs to be tackled in order to increase its efficiency and ultimately to make it commercially viable.

9 Statement of Objectives

Authors: M.A. Haji Md. Said, Y.Q. Yao & A. Jarušauskas

9.1 Main Objectives

Authors: M.A. Haji Md. Said

As mentioned (and discussed) time and time again in the preceding sections, the ultimate aim of the project is to build a commercially viable small-scale biofuel production system that can be implemented within a hotel establishment, on board a cruise-ship, or within a community or neighbourhood where the amount of organic waste generated will be significant enough for the system to be implemented.

Upon analysing the prototype that the group inherit from Team 09/10, the group drafted a proposed plan of action that was discussed in simultaneously with the analysis of the inherited prototype in Section 8.1, a summary of which is presented in Table 9-1.

Aspects	Aims
Electrical and Control System	• Increase Automation. • Redesign the Heating System. • Redesign the Inherited Control System Hardware and Firmware.
Mechanical System	• Reconsideration of or redesign the Reflux Still. • Implementation of Filtration System. • Reconsideration of or redesign the Impeller System. • Maximising the space used. • Utilising the 'Free' Energy.
Bio-Chemical Optimisation	• Research into alternative methods of the feedstock Pre-Treatment. • Research into the availability of suitable enzymes that have lower optimum working temperature similar to that of the yeasts. • Determine the optimum length of time for the fermentation process.

Table 9-1: Summary of Project Aims.

9.2 Project Management Structure

Authors: M.A. Haji Md. Said

Towards the beginning of the project, the group arranged a meeting with the project supervisor and discussed the matters of the Management Structure, the conclusion of which is presented in Figure 9.1 and a summary of the post holders is presented in Table 9-2.

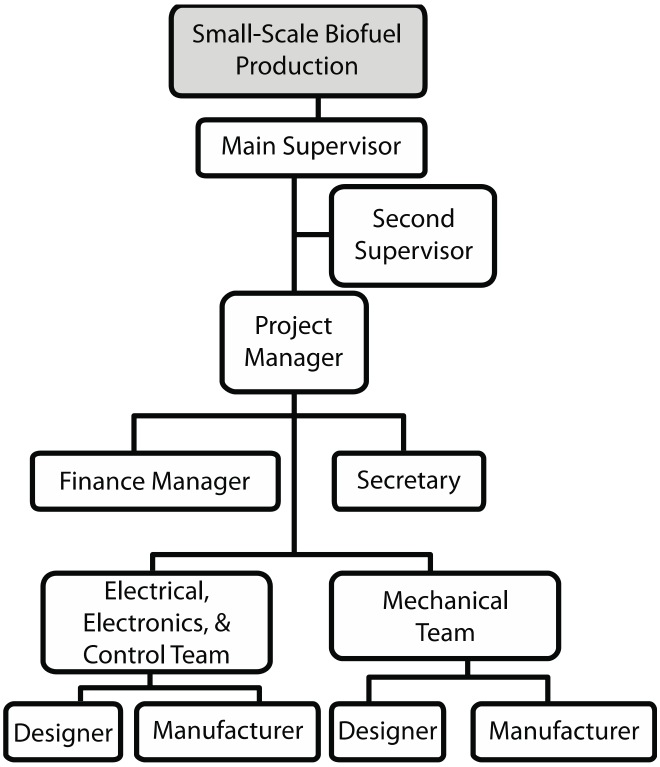


Figure 9.1: Project Management Structure

Post	Post Holder
Main Supervisor	Dr. Lional Ripley
Second Supervisor	Dr. Christopher Long
Project Manager	Armandas Jarušauskas
Secretary	Mohammad Ariffin Haji Md. Said
Finance Manager	Chitom Obi
Electrical, Electronics, & Control Team	• Armandas Jarušauskas • Chitom Obi
Mechanical Team	• Mohammad Ariffin Haji Md. Said • Yuan Qing Yao

Table 9-2: Summary of Post Holders.

9.3 Initial Project Management Plan Proposal

Author: Y.Q. Yao & M.A. Haji Md. Said

9.3.1 Project Milestones

9.3.1.1 Research

Research is an essential way to get information that the group needed; this is especially the case since the project is in its third year. Therefore, the main goal in doing the research is to gain an understanding of the processes involved in this project based on the work that has been done by the previous groups and also to attempt to acquire the knowledge needed to improve the system. The research will include different aspects such as chemical, electrical, electronics, control system and mechanical, which will be done by the team members with an appropriate work breakdown structure.

9.3.1.2 Design Prototype

During the research stage, the group will have had regular meetings to discuss the findings of each member of the team on their given tasks as well as to discuss the next logical step to take. The aim of the design process is to automate as well as increase the efficiency of the system with various ideas categorised by the different aspects of the project (Table 9-3).

Aspects	Ideas
Chemical	• Optimising the production of Ethanol. • Choosing better strains of enzymes and yeasts.
Electrical, Electronics, and Control System	• Implement PH and Temperature Control System. • Design and program the Control System.
Mechanical	• Better structural design. • Reduce unnecessary energy consumption and loss. • Implement Insulations.

Table 9-3: Proposed Design Aim and Ideas.

9.3.1.3 Build or Modify Prototype

At this stage, the group would apply the knowledge acquired during the research stage to implement any changes and modifications made to the system during the designing process.

9.3.1.4 Prototype Testing and Refinement

Once the building and modification process are completed, the prototype would be run and tested. Hence time should be allocated in order to run the built prototype and samples of ethanol produced must be collected and analysed, after which the group will once again organise meetings to discuss further improvements that could be done to the built prototype.

9.3.1.5 Further Analysis

In addition to analysing the collected samples of ethanol from the test runs, other aspects such as heat transfer analysis, energy balance, and efficiency calculations will also be required. Hence further prototype experimentations may need to be done, although it must be noted that all experimentations must be done prior to the commencement of the final task of writing the final report.

9.3.1.6 Write Report

The report (as set by the Engineering and Design Department at the University of Sussex) should be at least 25,000 words and the group aimed to complete the report before the end of the second (spring) term of the 2010/2011 academic-year. The report should detail the entire project, which includes (but is not limited to) the aspects presented within this chapter especially on the achievement of the aims and objectives.

9.4 Initial Budget Proposal

Author: A. Jarušauskas

It is hard to accurately estimate the cost of building and/or modifying the final prototype. Table 9-4 illustrates the current group's initial estimate on the total cost of components. However, manufacturing services could result in some additional expenses, but these will have to be confirmed at a later stage. It is also worth mentioning at this point that the numbers presented in the table should represent the worst case scenario and, all being well, the group aims not go over budget.

Part	Quantity	Cost (£)
Electrical		
Heater element	1 or 2	20
SCR/TRIAC	1 or 2	10
Relay	1	10
Other components		40
Electronic		
Microprocessor	5	20
Operational amplifier	5	15
Temperature sensor (PCB)	5	5
Thermocouples	5	30
LCD	1	20
Project enclosure	1 or 2	20
Other components		40
Electromechanical		
Solenoid valve	4	20
Mechanical		
Pressure relief valve	2	10
Filtration system	1	50
General rig modification & services		400
		Total: £710

Table 9-4: Initial Proposal on Budgeting.

10 Design

Authors: Y.Q. Yao, M.A. Haji Md. Said, C. Obi, & A. Jarušauskas

This chapter will present different aspects of the designed system. The discussion made within this chapter will be divided into three main sections starting from the discussion on the mechanical and structural design. This will be followed by some discussions on electrical and electronics design and the chapter will be ended with some discussions on the design of the control system.

10.1 Mechanical and Structural Design

Authors: Y.Q. Yao & M.A. Haji Md. Said

As discussed in the previous sections, the group aims to design a fully automated and energy efficient prototype. The group has done a significant modification (which will be discussed in the succeeding sections) to the prototype that was inherited from Team 09/10. This the group thought has significantly move the project towards achieving the full automation of the system.

10.1.1 General Design Concept

Team 09/10 have designed and implemented quite a few components, which include the impeller, motor, and the baffles, amongst others. This enabled the group to focus more on the general structural design of the prototype. One of the main considerations in the structural design of the prototype is the idea of utilising the 'free' energy i.e. the earth's gravitational pull. Hence, in order to achieve this the different elements of the prototype would need to be rearranged so that each of the four main processes involved is technically on top of one another and were interconnected. Therefore in doing this, there will be no need for the use of any pumping equipment to mobilise the slurry from one place to another, which will of course reduce total energy consumed by the prototype.

In terms of increasing the automation of the prototype, the group had to consider any post-processing activities that needed to be implemented into the system such as cleaning all the equipment as well as collecting and discarding the waste. The idea of the full automation is so that the operator would only need to feed in the feedstock and start the prototype, the rest of the processes will then run on their own accord (based on the programmed control system) and also the prototype will cleanse itself ready to run another production cycle.

10.1.2 Structural Design

In achieving the goal to utilise the 'free' energy i.e. the earth's gravitational pull, the mechanical team acquired (and modified) a domestic flat-packed shelving unit from a local (Brighton) DIY store; this was done with the suggestion from Dr. Ripley, the project's main supervisor. This enabled the team to 'stack' each component of the prototype on top of each other, which is illustrated in Figure 10.1.

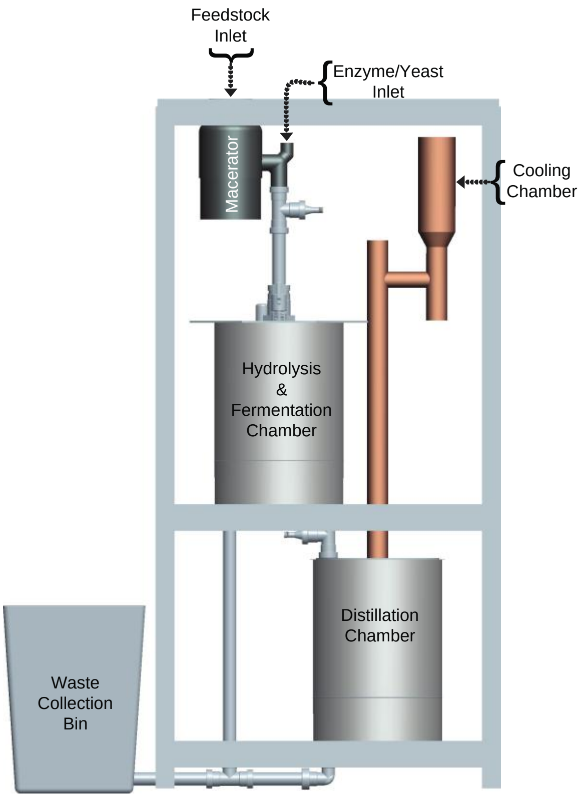


Figure 10.1: Illustration of the Built Prototype.

Not only does this structural arrangement allows the utilisation of the earth's gravity pull to mobilise the slurry from one component to another, it also enables the group to achieve their second goal, which is optimising the use of space as this arrangement requires less floor space or area.

As can be seen in Figure 10.1, the macerator is fixed onto the top shelf and is connected to the first containment vessel using domestic plumbing pipes, allowing the slurry to flow from the macerator into the containment vessel (hydrolysis and fermentation chamber). The vessel on the other hand is fixed onto the second shelf using the rods the group inherited from Team 09/10. The slurry is kept inside this vessel using industrial ball valves (Figure 10.2) in order to enable the hydrolysis and fermentation processes to take place.

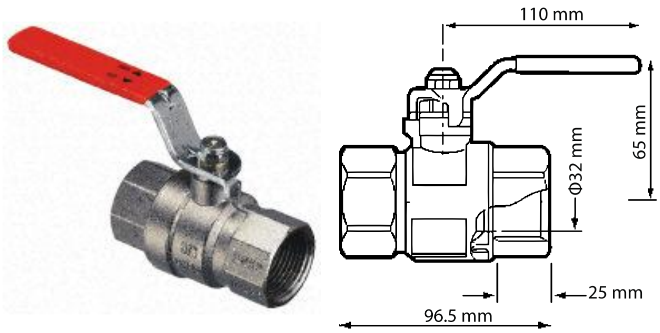


Figure 10.2: Illustration of the Industrial Ball Valve used, Image sourced from (RS Components Ltd.)

In terms of feeding enzymes and yeasts into the system for the processes of hydrolysis and fermentation, the group thought that the spare (overflow) connection of the macerator could be used (as indicated in Figure 10.1), otherwise there is also an alternative way which is by utilising the water inlet connection between the macerator and the vessel (Figure 10.3), which can be uncapped.

Figure 10.3: Water Inlet Connection to the Vessels.

Once the hydrolysis and fermentation processes are done, the ball valve connecting the hydrolysis and fermentation chamber to the distillation chamber could be opened and the fermented slurry is allowed to flow into the distillation chamber where it is contained using another ball valve. Once the distillation process is done, all the ball valves could then be opened allowing waste matters to flow into the waste collection bin and the cleansing process could then be run.

The only main modifications done to the domestic shelving unit were on the wood shelving panels, where holes had to be drilled (illustrated in Figure 10.4). This was done in order to allow the interconnection of the equipment using pipes as well as to enable the group to fix all the equipment in position. The four 50 mm diameter holes on the middle and bottom shelves are designed to align to each other to enable the connection of pipes whereas the four 5 mm diameter holes on the middle shelf surrounding the 50 mm holes are the slots onto which the rods are used to fix the hydrolysis and fermentation vessel onto the shelf. The rectangular hole is to allow the Reflux Still to pass through, whilst the square hole on the top shelf is where the macerator is the slot onto which the macerator is fixed. The reason why the bigger holes are designed to be quadrilateral is to ensure the ease of the manufacturing process.

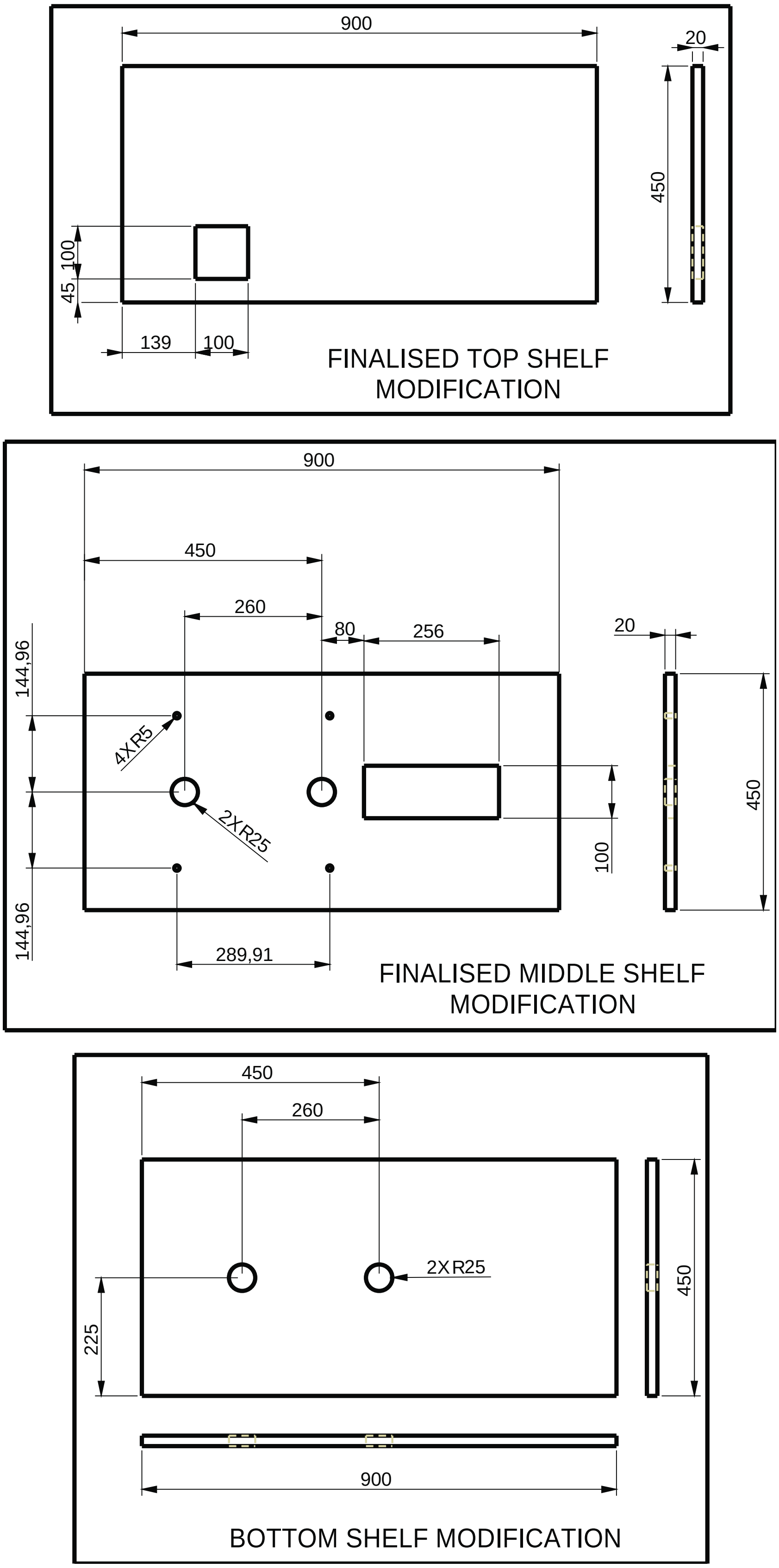


Figure 10.4: Technical Illustration of the Shelves Modifications i.e. Cavity/Holes Design.

Following the recommendations by Team 09/10 to reduce the size of the distillation chamber, the group have acquired a new tea-urn similar to the tea-urn implemented by Team 09/10 as the hydrolysis and fermentation vessel, for reasons which will be clear in the next chapter. In order to fit the ball valves onto the vessels another simple hole drilling modification was done to the bottom of the tea-urns. Figure 10.5 illustrates the modifications done to the hydrolysis and fermentation containment vessel. A similar modification was done onto the distillation vessel except that the distillation vessel only requires one hole at the bottom of the tea-urn.

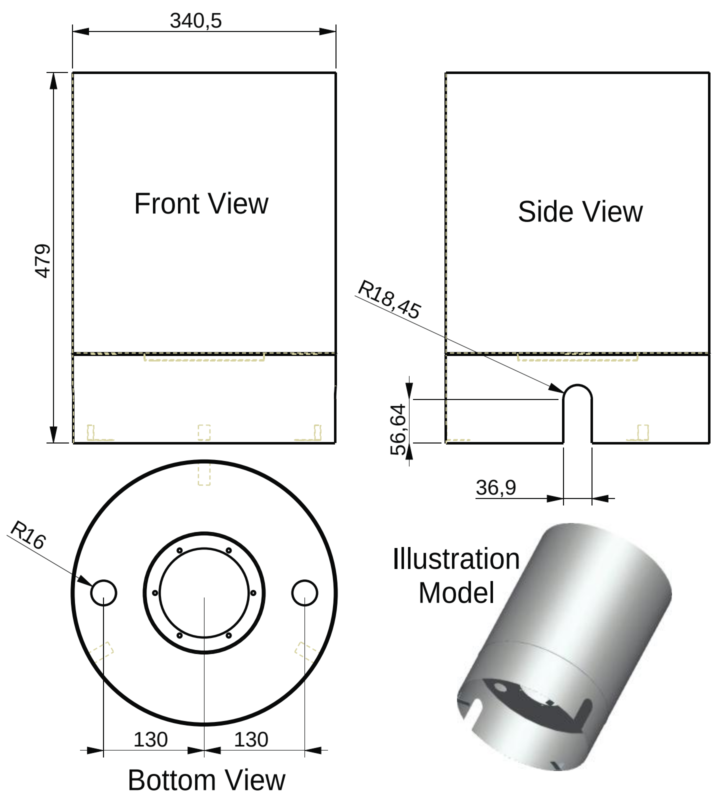


Figure 10.5: Modifications to the Hydrolysis and Fermentation Vessel.

Another modification done to the tea-urn is the creation of the holes on the sides of the tea-urn (Figure 10.5), which is done to ensure that the lever to the ball valve is kept accessible (Figure 10.6).

Figure 10.6: Ball Valve Lever Accessibility.

The ball valves are fixed onto the vessel using industrial hexagon nipple connector (Figure 10.7) that are modified i.e. one half of the screw part was cut off leaving the other half to fix the ball valves to the vessels.

Figure 10.7: Industrial Hexagon Nipple Connector Acquired for the Project, Image source (RS Components Ltd.)

A fine wire mesh (taken from a domestic kitchen sieve) was glued onto one of the modified hexagon nipple connectors that fix the ball valve that connects the two vessels together. This acts as a filtration system to keep the solid waste from the hydrolysis and fermentation processes (unhydrolysed and unfermented potatoes) inside the first containment vessel whilst allowing the fermented liquids to flow into the distillation chamber to be purified.

As for the damaged heating element, the group replaced this with a heating plate sourced from a portable electric hob, which the group believed was used by Team 08/09 as the heater for their distillation system. The original tea-urn heating element was modified where the resistor element that can be seen on the underside of the tea-urn was cut and the surface was then flattened. The group then used a specialised liquefied metal-to-metal adhesive to fix the heating plate onto the base of the tea-urn used as the containment vessel for the hydrolysis and fermentation processes.

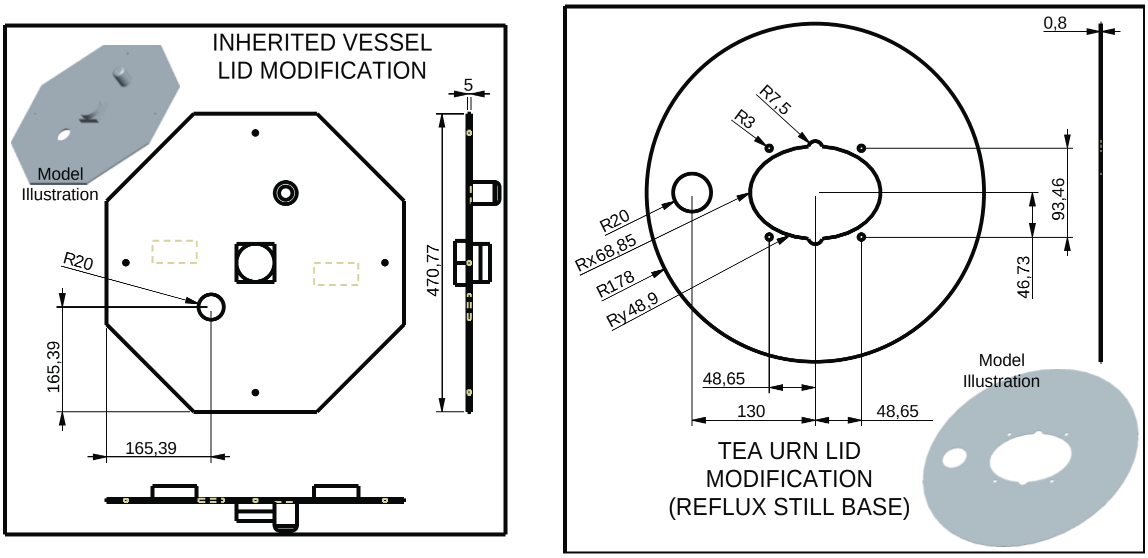


Figure 10.8: Vessel Lids Modifications.

The final modifications were done onto the lid of the hydrolysis and fermentation vessel that the group inherited from the previous group as well as the original lid from the newly acquired tea-urn (Figure 10.8). The modification done on the inherited lid is to enable the pipe connections between the macerator and the containment vessel for the hydrolysis and fermentation processes, whilst the modification done on the tea-urn lid (which is used as the base of the Reflux Still) is to allow the pipe connections between the two main vessels.

10.1.3 Water Supply Connections

Water supply connections are an essential part in the design consideration, especially due to the fact that all of the four main processes require water supply (as discussed in the previous chapters). In addition to that, the final cleansing process also needs a good supply of water to ensure that all the waste is flushed out preparing the rig for the next run.

Figure 10.9: Hozelock Y Connector,

Image sourced from (B&Q Plc., 2011)

Figure 10.10: Hozelock End and Tap Connectors,

Image sourced from (B&Q Plc., 2011).

The supply of water is taken from the mains water within the premises that the project is located. The group then just utilised the garden hosepipes (inherited from the previous groups) to connect the water supply to all elements of the prototype. The group utilised some *Hozelock Y Connectors* (Figure 10.9) together with some *Hozelock End and Tap Connectors* (Figure 10.10) to split the only mains water supply (Figure 10.11, Figure 10.12 and Figure 10.13) in order to provide water supply connections to the different parts of the prototype that requires it.

Figure 10.11: Mains Water Supply.

Figure 10.12: Mains Water Supply Connections.

Figure 10.13: Water Supply Splitter Connections

Figure 10.14: Solenoid Valve Connections.

A solenoid valve (Figure 10.14) is connected between the split water supply and each component of the rig that requires it, namely the macerator, the hydrolysis and fermentation vessel, the distillation chamber and the cooling chamber of the Reflux Still. The solenoid valve (which operation is governed by the Control System) is used to control the water supply into the prototype.

Figure 10.15: Connection between the Cooling Chamber of the Reflux Still and the Water Butt.

In addition to that, the group thought that it would be best to collect the 'used' cooling water from the cooling chamber of the Reflux Still using the water butt (Figure 10.15) that the group inherited from the previous groups. This the group thought gives reasons towards future research on the utilisation of the 'used' cooling water rather than sending it to the drain and wasting them. This would definitely increase the efficiency of the built prototype and reduce waste wherever possible.

10.1.4 Thermocouples

A total of five thermocouples are installed onto the prototype equipment in order to monitor the temperatures of the system. A summary of the functionality of each thermocouple is presented in Table 10-1. It is crucial to monitor the temperatures during the different processes, not only to ensure the optimal productivity but also to ensure that the system does not get overheated, which may result in the failure of another component.

Thermocouple	Location	Functionality
1	Inside the hydrolysis and fermentation chamber.	To monitor the temperature of the slurry during the hydrolysis and fermentation processes.
2	Fixed to the heater on the underside of the hydrolysis and fermentation chamber.	To monitor the temperature of the heater, which in return enables the heater to be controlled in order to maintain the temperature of the slurry inside the vessel.
3	Inside the distillation chamber.	To monitor the temperature of the fermented slurry during the distillation process.
4	Fixed to the heater inside the distillation chamber.	To monitor the temperature of the heater, which in return enables it to be controlled in order to maintain temperature of the slurry inside the vessel.
5	Inside the Reflux Still.	To ensure that the temperature inside the Reflux Still is at the boiling point of Ethanol i.e. at 78°C.

Table 10-1: Summary of the Functionality of the Thermocouples.

Further discussions on the temperature control system will be presented in the subsequent sections.

10.2 Electrical (Electronics) Design

Author: C. Obi

As mentioned in the previous chapters, producing bio-ethanol from (complex) sugars require various processes, which consequently required quite a number of different equipment. This section will present the design and use of components such as relays, optocouplers, TRIACs and TRIAC drivers, used to control the various equipment intended for the use in this project. The discussions will detail the means by which the control signals from a microcontroller are made available to all the equipment and how they are used. The section will be divided into four main sub-sections beginning with some design considerations before moving on to discussions on the design implementations. The section will then move on to discuss the initial and final design of the electrical and electronics system.

10.2.1 Design Consideration

As discussed in the previous sections, the ultimate aim of the project is to produce a fully automated small-scale biofuel production system, which basically means that the prototype would need to be designed so that it could run on its own accord without extensive and constant monitoring other than adding the feedstock, enzymes and yeasts into the prototype and pressing the 'start' button.

With this in mind, the group set out to research on the possibility of achieving this goal. Upon discussions between the project main supervisor and the electrical, electronics and control system team, it was decided that a microcontroller would be used for the overall control of the system, which includes taking the required measurements and controlling the different processes involved within the system. Thus optocouplers were needed to electrically isolate as well as couple the control signal from the microcontroller to the electrical circuit.

Almost all of the equipment such as the heaters, solenoid valves, macerator and motor for the stirrer required an AC mains supply, in order to control the AC mains supply to the different equipment, relays were used to switch all the equipment (except the two heaters) 'on' and 'off'. The supplies of the AC mains supply to the heaters however will be controlled by TRIACs, which will be further discussed in the subsequent sub-sections. This is because the TRIACs will be able to produce a precise control of power due to the fact that it can be triggered by enabling their individual gates at the desired times. Due to the fact that the two heaters would require the supply of electricity at 240 Volts, it was necessary to isolate the high voltage circuit from the low voltage ones. To achieve this i.e. to avoid such a high voltage being fed into the low voltage part of the circuit, TRIAC drivers were used to insulate the high voltage circuit from the low voltage circuit (Hoult, 2010).

Relays were also used to control the power supplied to the solenoid valves, the macerator and the motor, due to its ability to allow one circuit to work independently of the others. In the case of the project, the low voltage side of the circuits would be used to switch 230V AC mains circuit.

A Zero-Crossing Detector (ZCD) circuit was also included in the design; this was done using alternating current supply, Diode Bridge, and comparators. The signal from the ZCD was then fed into the microcontroller and used to control the two heaters. In order to implement all of the control system elements into the built prototype, the electrical, electronics and control system team decided to design and built a printed circuit board, which will be described in the subsequent subsections.

10.2.2 Implementation

As mentioned previously, the group decided that it was best to implement the use of printed circuit board (PCB) in the project for clearer and easier understanding of the control process. In order to achieve this an Electronic Design Automation (EAD) software package for PCB, FPGA and embedded software, called Altium Designer was used. The software allows the team to produce schematic drawings that were used to design the layout of the PCBs.

10.2.3 Initial Design

The schematic diagram of the initial PCB design is attached in Appendix D: Schematic Diagram of the Initial Circuit , as can be seen in the diagram of the design included the control circuit of all the components on the same board which includes both the high voltage (AC mains) supply and the low voltage components. Also it was designed such that the AC supply for the ZCD is taken directly from the Live and Neutral of the AC mains supply to the board. However, due to safety issues especially on dealing with mains supply, it was suggested by one of the technicians at the university student workshop that the AC supply for the ZCD should be obtained from a 10 Volts AC power supply unit (PSU), a component that was supplied by the workshop.

The design was also done in such a way that the AC supply to the board would be regulated to provide the low voltage needed for some components using electronic components such as the transformer, rectifier, filter, and regulator, which may well prove to be complicated. An alternative way to provide the low voltage circuit components would be to use another power supply unit (PSU) already present in the workshop or otherwise the group would need to acquire a ready-made power supply unit. After much consideration, it was concluded that low voltage power supply should be purchased.

During the initial design, the plan was to only use three solenoid valves, however in the course of the structural build, the group discovered that an extra solenoid valve was needed. Considering the fact that the PCBs were already printed (and all the components were already soldered onto the board) at the stage that this was discovered, the electrical, electronics and control system team decided that the relay which was originally intended to provide power supply to the macerator will be used for to provide power to this final valve. Hence, this would mean that the macerator would need to be operated manually, which the group thought would not pose any major problems as it is only required at the beginning of the production process. Although an alternative solution would be to connect the power supplied to the solenoid valve (used to control the water supply into the macerator) parallel with that of the macerator controlling them with a common socket. This is possible due to the fact that both the solenoid valve and the macerator will be required to operate simultaneously. However, considering the limited time (at which the discovery was made) as well as the concerns to minimise the amount of live mains connection, the latter alternative solution was not implemented. See the figure below for block diagram showing the initial design.

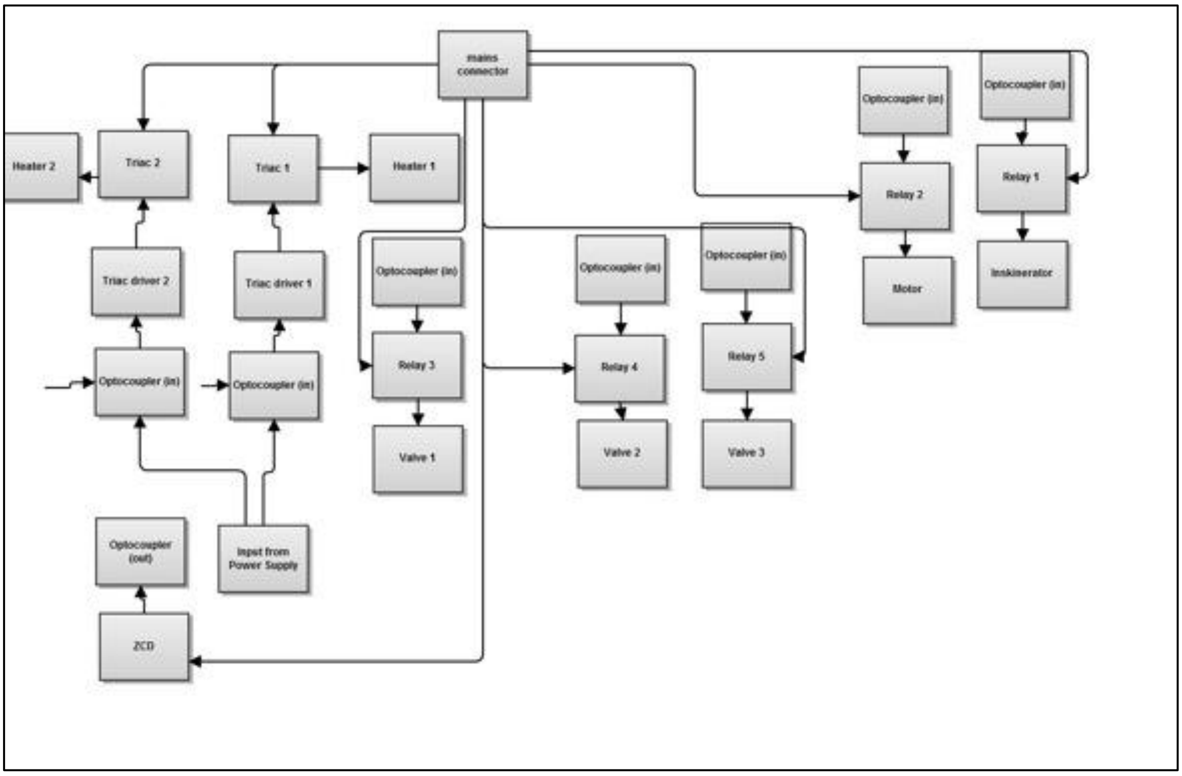


Figure 10.16: Block Diagram of the Initial Design of the PCBs.

10.2.4 Final Design

After much consideration based on safety related issues, the equipment to be used and connections to be made, it was decided that at this stage it would be a good step to split the circuit design into two parts depending on their voltage requirement and usage. Hence the initial schematic design was divided in two, one of which is the low voltage circuit (presented in Appendix E: Schematic Diagram of the Low Voltage Circuit) and the other is the high (AC mains) voltage circuit (presented in Appendix G: Schematic Diagram of the High (AC Mains) Voltage Circuit). The respective PCB design layouts are presented in Appendix F: Low Voltage Circuit PCB Layout and Appendix H: High (AC Mains) Voltage PCB Layout.

10.2.4.1 Optocouplers

Optocouplers are used to transfer electrical signals by making use of light waves to provide coupling with electrical isolation between its input and output. In the case of this project, on the input side is the control signal from a microcontroller, whilst the output side is connected to the relays and TRIACs drivers that needed to be controlled.

The optocoupler model chosen for this project was selected based on features such as cost and supply voltage output type. The optocoupler used in this project was Optek Technology's OPIA601ATU, a surface mount device which has a photodarlington output, and output that includes a resistor (located at the base) which is connected to the emitter of the second transistor. The implementation of the resistor improves the turn-off speed of the Darlington pair and also prevents current leakage through the first transistor from biasing the second transistor into conduction (Horowitz P. , 1989). Eight of these optocouplers were used in the design of the PCBs, seven of which were used to receive signals from the microcontroller whilst the remaining one is used to send the ZCD signal back to the microcontroller.

10.2.4.2 Relays

A relay is an electrically operated switch. With the right voltage applied across the coil of a relay, current flows through it creating a magnetic field that attracts a lever that alters the switch contacts (Hewes, 2010). Relays have two switch positions that are affected by the current passing through the coil, the two positions indicate either 'on' or 'off' and most have double throw switch contacts (Hewes, 2010).

To operate the solenoid valves and the motor (which are to be controlled by the relays), their respective terminal needs to be connected to the AC mains 'live' and 'neutral' connections. Therefore, the relay that is to be implemented into the system must be able to switch the power supply to the terminals 'on' (consequently turning the equipment 'on') upon receiving the control signal via the optocoupler, otherwise without the interception of the control signal the relay would stay dormant. Therefore, based on this the type of switching required is the Single Pole Double Throw (SPDT). The relay used was Multicomp's HRM-S DC9V, a type of relay that is purpose-designed for use in PCBs. The relay is designed with a Single Pole Changeover (SPCO), which is also otherwise known as SPDT and it has a specified maximum AC voltage of 250 V. Five such relays were implemented in the design of the PCB.

To establish the current necessary to provide the energy to the relay, a current source is needed which can be achieved using a single transistor (or a Darlington configuration). Using the single transistor, a relay can be connected to the collector circuit of the transistor, and in the case of the design in this project the relay is connected to the collector of the photodarlington transistor. When the photodarlington is turned 'on', it establishes a sufficient amount of current through the coil of the electromagnet and closes the relay (Boylestad & Nashelsky, 2002). To protect the photodarlington from being permanently damaged when supply is removed (as a result of voltage induced in the coils), a diode is placed across the relay (Boylestad & Nashelsky, 2002). Hence, this combination of the diode and photodarlington output (in this case) acts as the relay driver. The diode used was the IN4148, a small signal diode.

10.2.4.3 Optocouplers and Relay Connections

The diode side of the optocouplers were connected to the process control-unit board; the design and calculations of which are discussed in the subsequent sections. Apart from the diodes, there were no additional components required in the connection of the optocoupler to the relay. Figure 10.17 below shows one set of connections, and there are five of these in the final design.

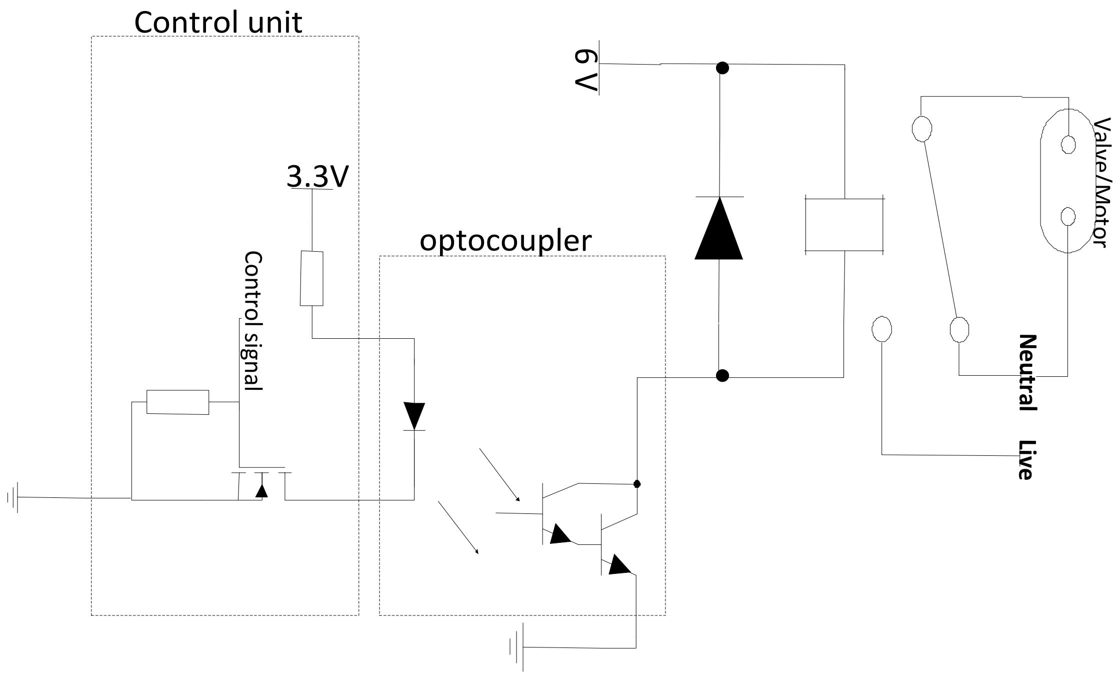


Figure 10.17: Optocoupler-Relay Connections.

10.2.4.4 TRIAC Driver

Electrical isolation is often a requirement when using a power TRIAC; this can be achieved using an optocoupler designed for such applications. This ensures that the control circuit on the PCB will remain electrically isolated from the mains, which is important so as to prevent any high or rapidly changing voltages on one side of the circuit to affect the other side adversely. The MOC3023-M optocoupler was used due to the fact that as it has a photoTRIAC output and its characteristics meet the needs of the design.

> *"It belongs to the MOC30XX family of random phase (non-zero crossing) TRIAC drivers which consist of an aluminium gallium arsenide infrared LED, optically coupled to a silicon detector chip" (Fairchild Semiconductor, 2003)*

10.2.4.5 Optocoupler and TRIAC Driver Connections

To limit the photodiode (LED) in the TRIAC driver, a resistor R was used the value of which can be calculated using the following formula:

$$R = \frac{(V_{DD} - V_{LED})}{I_{LED}} = \frac{6V - 1.2V}{20mA} = 240\ ohms$$

The forward voltage drop (V_{LED}) and the forward current for the LED (I_{LED}) were obtained from the datasheet of the TRIAC driver.

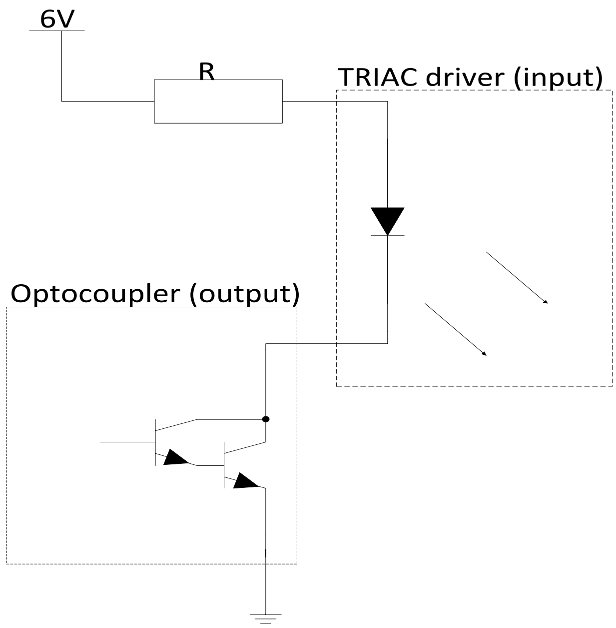


Figure 10.18: Optocoupler-TRIAC Connections.

The formula presented below was used to calculate the power dissipation in this resistor:

$$P = \frac{V_R^2}{R} = \frac{(6V - 1.2V)^2}{240} = 96.0\ \text{mW}$$

Based on the formula, the power dissipation value is obtained to be 96.0 mW, therefore a resistor with wattage rating of 250 mW can be used in this case.

10.2.4.6 TRIACs

TRIACs were chosen for the implementation of the power-supply control-element to the heaters. This is because they are ideal to be used where the mains power supply frequency is 50 Hz as well as in such applications that involves AC (power) control (switching 'on' or 'off') due to its ability to control the current flow over both halves of the alternating current cycle. The TRIAC is a three terminal semiconductor whose characteristics are similar to that of the thyristor except that it has a gate terminal for controlling its turn-on conditions in either directions of the AC, which means that it is a bidirectional device. It can be considered as two thyristors connected in anti-parallel. The TRIACs used was the BTA16-600BRG, which was selected because of its 16 Amps current rating which is ample enough to supply current to the heaters that only have a 13 Amps rating. In addition to that, the TRIAC was also chosen due to its insulated tab.

When the control signal is sent from the microcontroller, it generates a response in the optocoupler which in turn generates a response in the TRIAC driver, which controls the gate terminal of the TRIAC causing to it trigger the TRIAC or not.

10.2.4.7 TRIAC Driver and TRAIC Connection

> *"The MOC30XX TRIACs are capable of controlling larger power TRIACs with a minimum number of additional components" (Fairchild Semiconductor, 2003).*

In this case, the only additional components were the series gate resistors for each of the TRIAC-TRIAC Driver network.

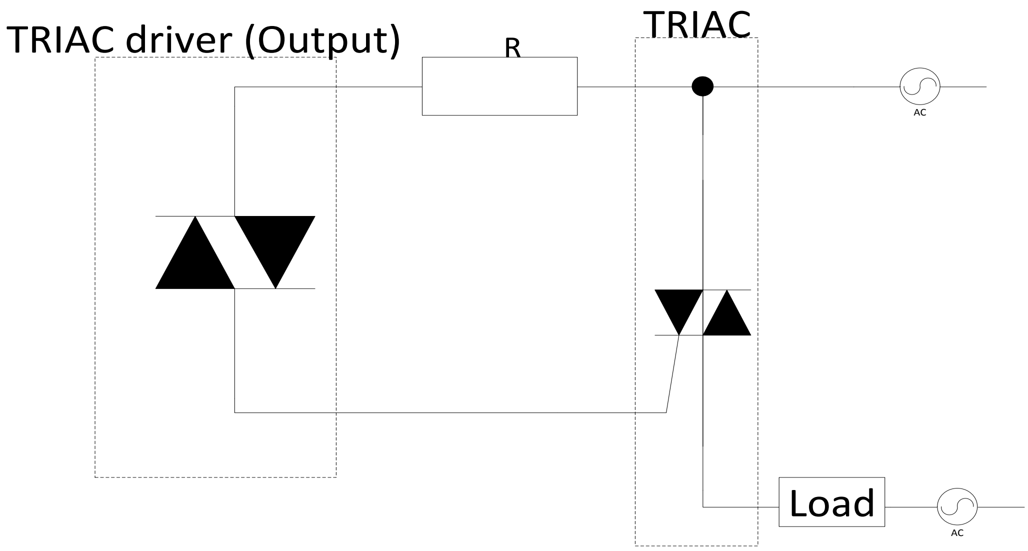


Figure 10.19: TRIAC-TRIAC Driver Connections.

To calculate the peak voltage of the AC mains and allowing for worst-case scenario, the calculation was done as follows:

$$V_p = 240 \times \sqrt{2} = 339.41\ V$$

To calculate the minimum value of this gate resistor, the following was used:

$$R_{min} = \frac{V_{pACline}}{I_{TSM}} = \frac{339.41}{0.6} = 565\ ohms.$$

Rounding the figure up to adhere with some standard values, the value of R_{min} should be taken as 620 ohms.

10.2.4.7.1 Resistor wattage

"To calculate the Root-Mean-Square (RMS) power through the resistor, let's use the 50 us as the pulse time, but increase the current to the 50 mA maximum specified for the TRIAC" (Cooley, 2005).

Square of maximum current is $(50\ mA)^2 = 2500\ \mu A^2$. Therefore the average over the time is ${}^{50\mu s}/_{20ms}$ for the AC half cycle. Hence the average squared current is $2500 \times {}^{50\mu s}/_{20ms} = 6.25\mu A^2$. Taking the square root of that the RMS should be taken as 2.5 mA. Based on these information, the RMS power could then be calculated and is presented in the formula below:

$$RMS\ power = I^2R = (2.5\ \text{mA})^2 \times 620 = 3.875\ \text{mW}$$

Therefore, since this power is below 1/4 W, resistor with wattage rating of 250 mW can be and in fact resistors with such wattage rating have been implemented in the design of the control system.

10.2.4.8 Heat-Sink

For safety purposes as well as to ensure the protection of the semiconductors, the TRIACs were mounted on a large heat-sink, which is an aluminium plate that had three holes drilled into it. Two of the holes were used for the TRIACs, whilst the remaining one was used for earth bonding. This direct mounting was made possible by the fact that the TRIACs used had insulated tabs, which allows for much safer installation than non-insulated devices. Care was taken during the final assembly to ensure unit is completely safe. For further discussions on the thermal aspects of the design, readers are referred to Appendix I: Thermal Design for TRIAC.

10.2.4.9 TRIAC and Electrical Connections

After the TRIACs had been safely mounted on the heat-sink, their terminals were connected as designed, which is illustrated in Figure 10.20. For the electrical wirings, hook up wires were used for the sockets and the 'power in' plug as it can stand a current flow of 13A. The other connections were made using plastic connectors and the wires were sleeved where necessary. These connections were enclosed in an earthed plastic box for safety precautions. The sockets and plug cables were fed into the box via three holes on the box and were held in place by suitable strain relief mechanism.

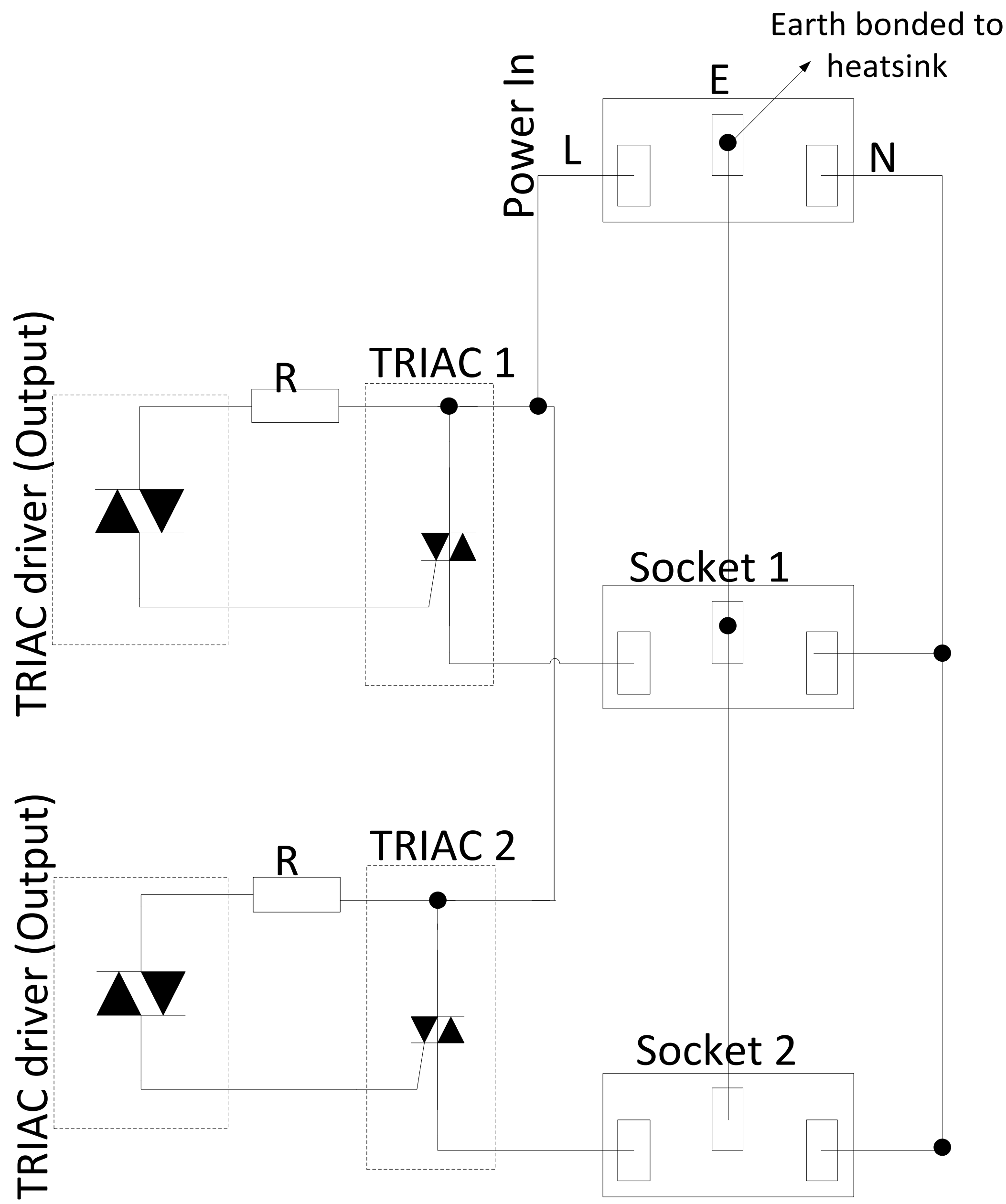


Figure 10.20: TRIAC Driver Outputs, TRIACs, and Socket Connections.

10.2.4.10 Motor

There were neither any changes nor modifications towards the motor and impeller (termed by the Laxman et al (Team 09/10) as down-pumping impeller (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010)) designed and utilised by the previous groups who has undertaken the project. Together they make up the agitation system for the hydrolysis and fermentation processes, which allows for a consistent and even distribution temperature, enzymes and yeasts. A small

AC motor is used to drive the down-pumping impeller system (both of which are mounted on the tank lid) and to aid the mixing processes baffles were installed on the vessel walls (Laxman, Lane-Serff, Hitchcock, Maunsell, & Austick, 2010). The motor used was an MV86111 reversible synchronous AC motor with an MRIG02 gearbox. The electrical connection for the motor is shown in Figure 10.21, which was sourced from the equipment datasheet. The two terminals to the left are connected to the 'live' and 'neutral' connections of the AC mains via a relay together with a single pole double throw switch used to provide the required switching needs.

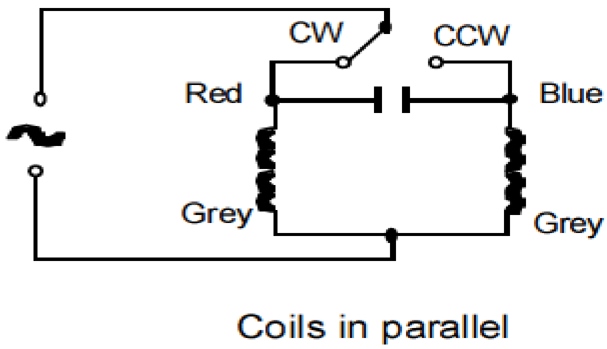


Figure 10.21: Motor Connections.

10.2.4.11 *Solenoid Valves*

The solenoid valves were to be used to control the flow of water supply into the system during the production process. The valves purchased (and hence used) for use in this project were a 'two way water solenoid valve with a 240 V_{AC} coil', which is a compact solenoid valve that is suitable for fluid and gas handling applications. It has a power rating of 4 Watts and has an operating pressure range of between 0.2 and 10 bars. Four such valves were purchased for this project and connections to the relay involved the use of terminal blocks (on the PCB) and insulated crimp terminals on the valve terminals.

10.2.4.12 Zero-Crossing Detection (ZCD)

To implement the zero-crossing detection (ZCD) system, a combination of components was needed, which includes an AC mains supply unit, a bridge rectifier, a comparator, as well as some potential divider networks. A 10 V AC power-supply unit (PSU) was used, as it was readily available from the workshop, which is certified for electrical safety. The bridge rectifier used was the W08G-E4, which is a single-phase bridge rectifier that has a Peak Reverse Repetitive Voltage rating of 800 V. The comparator used was MCP6541-I/P i.e. a Push/Pull Comparator that requires a single power supply. The potential divider network (illustrated in Figure 10.22) was designed based on the value of the rectified voltage (i.e. 14 V) obtained during prior testing. A suitable input value was then fed into the comparator.

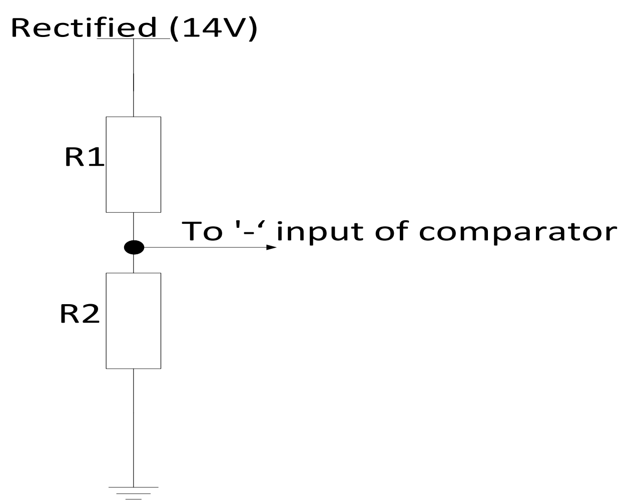


Figure 10.22: Voltage Divider Network for Obtaining the Input to the Comparator.

R2 was chosen to be 1000 ohms to provide 4 V input value and using the voltage divider formula $V_{R2} = {}^{R_2 \times V_{rec}}/_{(R_1 + R_2)}$, the value of R1 was calculated to be 51 kΩ.

The set up was first tested in the workshop with the initial configuration whereby the positive input of the comparator was connected to ground. The pulses obtained from the comparator seemed to have a little negative offset of the value 0.3 V. This negative offset is eliminated using a 6 V power supply together with a voltage divider which was used to obtain an input voltage of 0.3 V to correct the comparator's positive input so as to raise the reference point from ground a little bit.

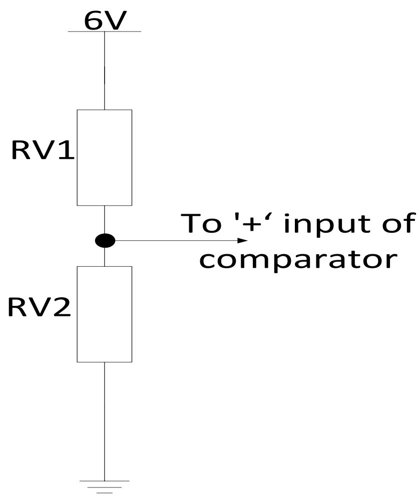


Figure 10.23: Voltage Divider Network set as the Reference Pont for the Comparator.

Using the voltage divider formula and choosing RV2 to be 10 kΩ, RV1 was calculated to be 190 kΩ.

The signal from the ZCD is made available to the control unit via an optocoupler; the output of the ZCD goes through an appropriate current limiting resistor and into the input side (LED) of the optocoupler.

The ZCD functionality was tested in the workshop with the aid of digital oscilloscopes that enables the waveform graphs to be displayed as well as saved as a retrievable file for further analysis. Figure 10.24 illustrates as well as compares the waveform of the rectified voltage to that of the comparator output. It can be seen that at any point where the AC voltage gets to the zero line, a pulse triggered by the comparator as expected.

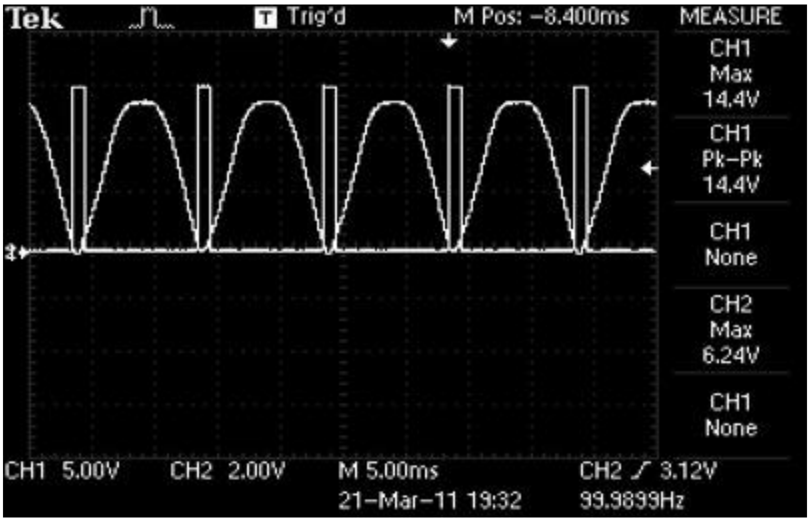


Figure 10.24: Comparing the Rectified Input to the Comparator Output.

Figure 10.25 shows the waveform obtained when the comparator output was been fed into the optocoupler via a resistor and this is also as expected.

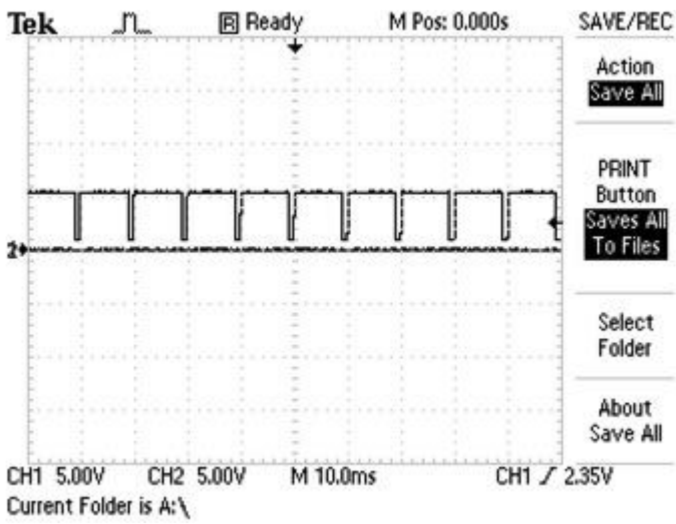
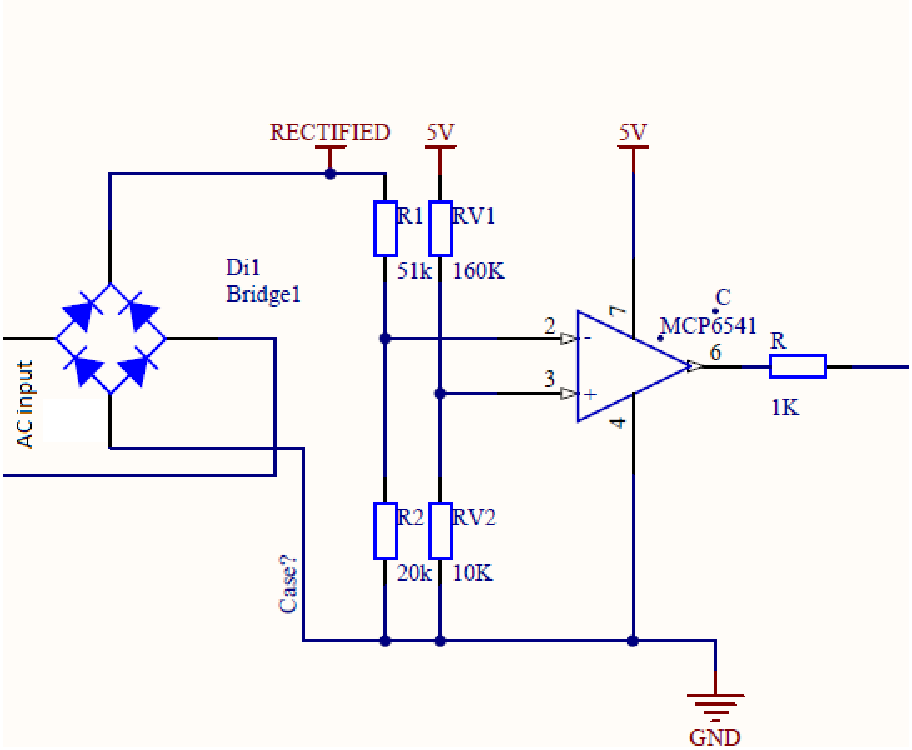


Figure 10.25: Output from the Optocoupler.



10.2.5 Electrical Safety Precautions

For the high voltage PCB IEC connector and cable were used to connect it to a mains plug. The IEC connector used was a 'DP flange fixing Vertical plug w/neon'. The connector is fitted with a 13 Amps fuse and has a neon lighting system to indicate the state of the component (i.e. 'on' or 'off'), it (the connector) is suitable for 10 A and 250 V_{AC}. In addition to that a 10 Amps fused IEC plug lead was used to connect the board to the wall mains socket.

The two PCBs were each enclosed in an earthed plastic box with the earth connection on the 'power in' plug. The two circuit boards were connected together and then earth bonded to the heat-sink. The block diagram of the overall design of the system in presented in appendices sections (Appendix J: Block Diagram of the Whole Design and the Corresponding Signals).

10.3 Process Control System (Electronics) Design

Author: A. Jarušauskas

The quality of biofuel produced depends heavily on the proper execution of all the relevant processes. The control unit was designed with an aim to provide optimal conditions for ethanol production as well as to minimise human intervention. This design section will go into details of the hardware and firmware design processes as well as manufacturing.

10.3.1 Hardware Design

10.3.1.1 Power Supply

The control board draws power from an off-the-shelf AC/DC power supply. This solution reduces cost and simplifies the overall system design. The on-board circuitry was designed to be flexible, and can operate with an input voltage ranging from 5V to 34V DC.

To achieve such a wide input voltage range, while maintaining high efficiency, a switching regulator was required. For this task, Micrel MIC4680 buck regulator was chosen. The part has an adjustable output voltage, which was set to supply 5 V, and an output current limit of 1.3A.

The device has the best efficiency when the input voltage is 12V, therefore a wall plug PSU capable of providing 1A at 12V was chosen.

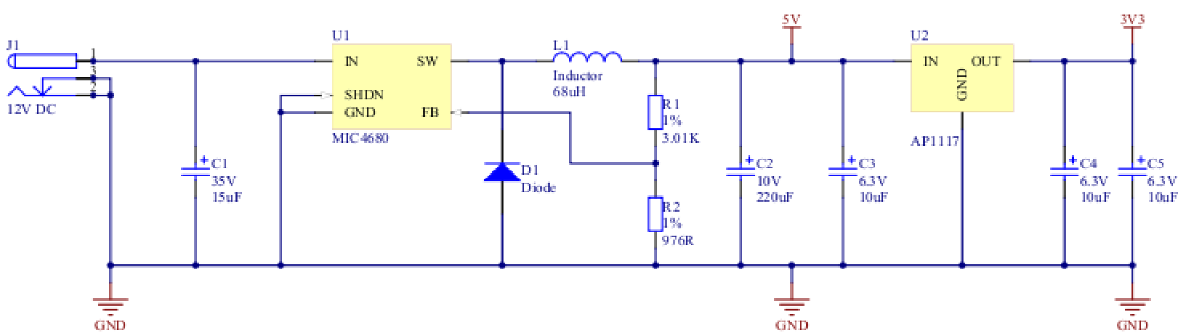


Figure 10.26: Power Supply Schematic.

The output from the switcher is fed into a 3.3V low drop-out (LDO) linear regulator. The reason for having two voltages is that the LCD requires a 5V supply to operate, while the PIC microcontroller and all other components use 3.3V supply.

Thermal design calculations for the switcher and the LDO can be found in [Appendix K: Thermal Design for the MIC4680 Buck Regulator] and [Appendix L: Thermal Design for the AP1117 LDO] respectively.

10.3.1.1.1 Theory of Operation

The buck regulator works by switching the pass transistor (labelled 1A Switch in Figure 10.27) on and off. The energy is stored in the inductor and the capacitor.

From (Horowitz & Hill, 1989):

"When the switch is closed, V_{out}-V_{in} is applied across the inductor, causing a linearly increasing current to flow through the inductor. When the switch opens, inductor current continues to flow in the same direction, with the catch diode now conducting to complete the circuit. The output capacitor acts as an energy "flywheel", smoothing the inevitable sawtooth ripple. The inductor now finds fixed voltage $V_{out} – V_{diode}$ across it, causing its current to decrease linearly."

The switch is operated at a fixed frequency of 200kHz, while the duty cycle is varied. The feedback voltage from the resistive divider goes to the fixed-gain error amplifier where it is compared to a 1.24V bandgap voltage reference. The output of the error amplifier is then compared to the 200kHz sawtooth waveform to produce a variable duty cycle output.

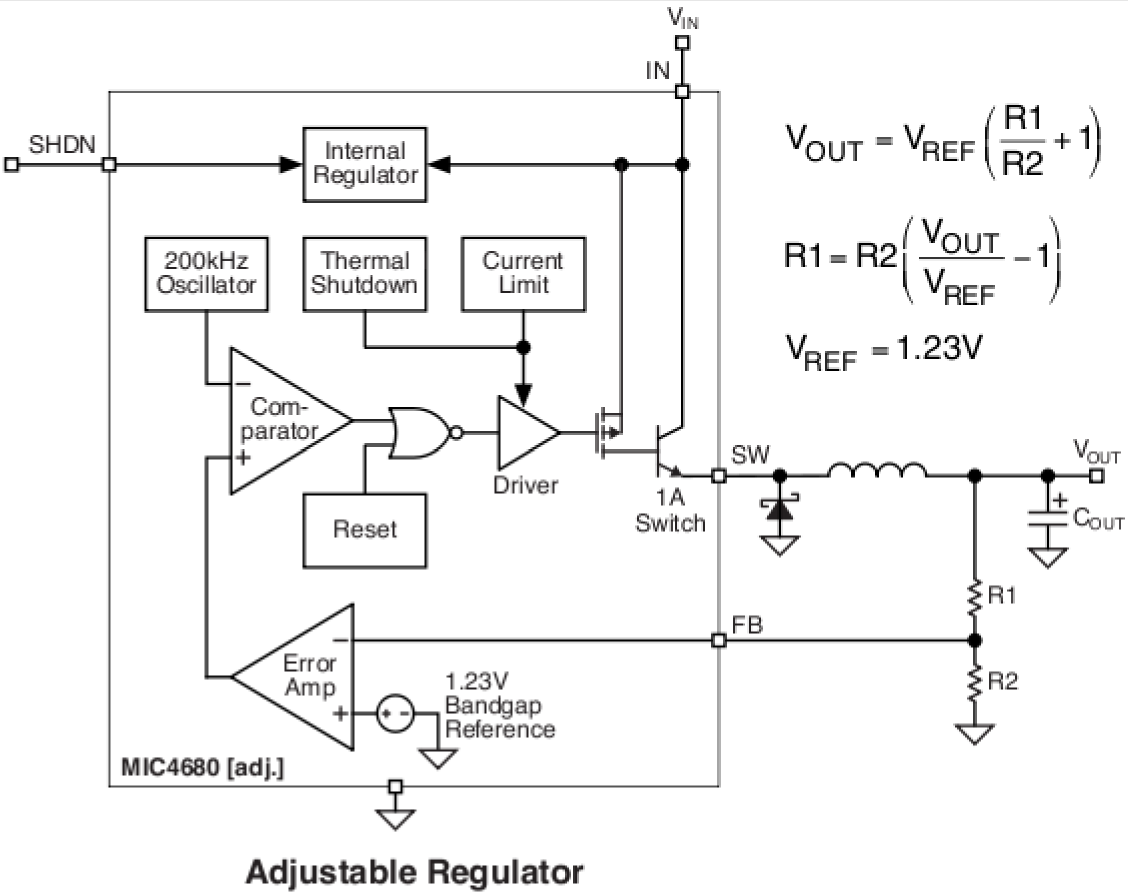


Figure 10.27: MIC4680 Block Diagram (Micrel Inc., 2008).

10.3.1.2 Temperature Measurement

10.3.1.2.1 Theory

Thermocouples are made of two different wires joined together. When there is a temperature difference between two junctions, a small voltage is generated, as shown in Figure 10.27. The thermoelectric effect describing such behaviour is called the Seebeck effect.

Type K thermocouples are made of nickel-chromium (chromel) and nickel-aluminium (alumel) wires (Nicholas & White, 1994). The typical temperature range for a K-type thermocouple is -200°C to 1350°C.

The typical thermocouple configuration for use with measurement equipment is shown in Figure 10.29.

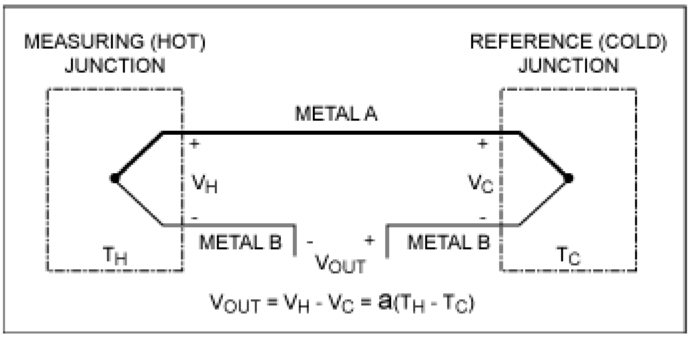


Figure 10.28: The Loop Voltage Generated by the Temperature Difference between Two Junctions in the Thermocouple is the result of the Seebeck Effect (Maxim Integrated Products).

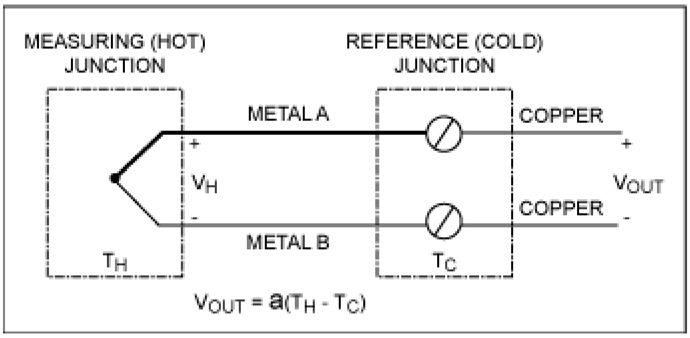


Figure 10.29: The Most Common Thermocouple Configuration has the Two Wires of a Thermocouple Joined at One End. The Open End of Each Wire is Connected to an Isothermic Connector Made of Copper (Maxim Integrated Products).

To convert the generated voltage to the temperature, one can make use of standardised functions and tables, such as in ITS-90. The numbers are based on cold junction temperature of 0°C. In most cases, however, it would not be convenient or viable to have a so-called ice-bath reference; hence the thermocouple voltage needs to be compensated.

The compensation is done by measuring the temperature of the reference junction, converting that temperature to a voltage (using a reference function), and adding the result to the thermocouple voltage.

The compensated potential can then be converted to temperature using an inverse function. The functions and coefficients are provided in the [Appendix M: Cold Junction Compensation for K-Type Thermocouples].

10.3.1.2.2 Signal Amplification

The control board was designed to measure temperature using K-type thermocouples. Since the generated voltage is very small, signal amplification is the first thing to do. From the table (Nicholas & White, 1994), the output of a type K thermocouple goes to about 10mV at 250°C. Since the analogue-to-digital converter is powered from 3.3V and has the same reference voltage, the signal should not be greater than 3.3V either. The limit was set to 3V (assuming maximum temperature of 250°C), and the gain calculated as follows:

$$A = \frac{3\text{V}}{10\text{mV}} = 300(V/V)$$

The amplifiers were set up in a differential configuration, as shown in Figure 10.30. The output of such a configuration is given as $V_O = (V_1 - V_2) \times \frac{R_1}{R_2}$ and the gain is set by the ratio of R1 to R2 (Storey, 2009).

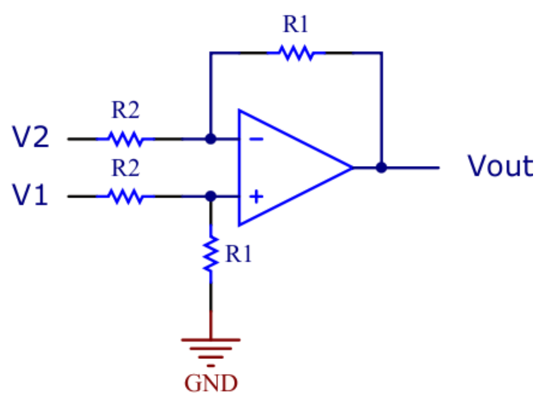


Figure 10.30: Operational Amplifier in a Differential Configuration.

The values for R1 and R2 have been chosen to be 300 kΩ and 1 kΩ respectively. In order to keep the gain as close to 300 as possible, the design uses resistors with tolerance of 0.1%.

Since the input signal magnitude is so small, conventional amplifiers could not be used, as their offset is too large. MAX4239 has a typical input offset of 0.1uV, which makes it suitable for such high precision operations.

10.3.1.2.3 Reference Junction

As mentioned in the theory section, the voltage generated by a thermocouple needs to be compensated, if the cold junction is not at 0°C. For this reason, a different type of temperature sensor, often a thermistor, is placed near the input terminal to measure the junction temperature. This temperature is then converted to electric potential, which is used to compensate the thermocouple voltage. [Appendix M: Cold Junction Compensation for K-Type Thermocouples] contains the theory for compensating K-type thermocouples.

In this design, MCP9701A linear active thermistor was used. The sensor outputs a voltage of 400mV at 0°C, and has a temperature coefficient of 19.5mV/°C. This type of temperature sensor is easy to use, as it does not require a Wheatstone bridge or amplification.

10.3.1.2.4 Data Acquisition

The signals from the amplifiers and the on-board temperature sensor are then connected to the Analogue-to-Digital Converter (ADC). The project was designed with a MCP3008, an 8-channel 10-bit Serial Peripheral Interface (SPI) ADC. The PIC microprocessor has a built-in A/D converter, but due to silicon errors, it was not suitable for this project. This issue is discussed in greater detail in section 10.3.1.4.1.

An ADC works by sampling the input voltage, comparing it to the reference, and outputting a digital number. The width of digital value, and the resolution is defined as the number of bits. In this case, the ADC has a 10-bit resolution, which given the reference voltage of 3.3V results in voltage resolution as follows:

$$V_{LSB} = \frac{3.3\text{V}}{2^{10}} = \frac{3.3\text{V}}{1024} = 0.0032\text{V} = 3.22\text{mV}$$

To convert the ADC reading to the actual voltage, the following equation can be used:

$$V_{ADC} = V_{LSB} \times VALUE$$

If the ADC gives us a binary digit, say 1000000000_2, which is the same as 512_{10}, then the sampled voltage is roughly equivalent to

$$V_{ADC} = 3.22\text{mV} \times 512 = 1.65\text{V}$$

10.3.1.3 Electrical Interface

The control board communicates with the electrical system in order to control various electrical devices, such as relays, motors, heaters, and valves. Due to high voltage being present on the electrical side, the two systems need to be galvanically isolated. For isolating low voltage signals, optocouplers are the simplest and cheapest solution.

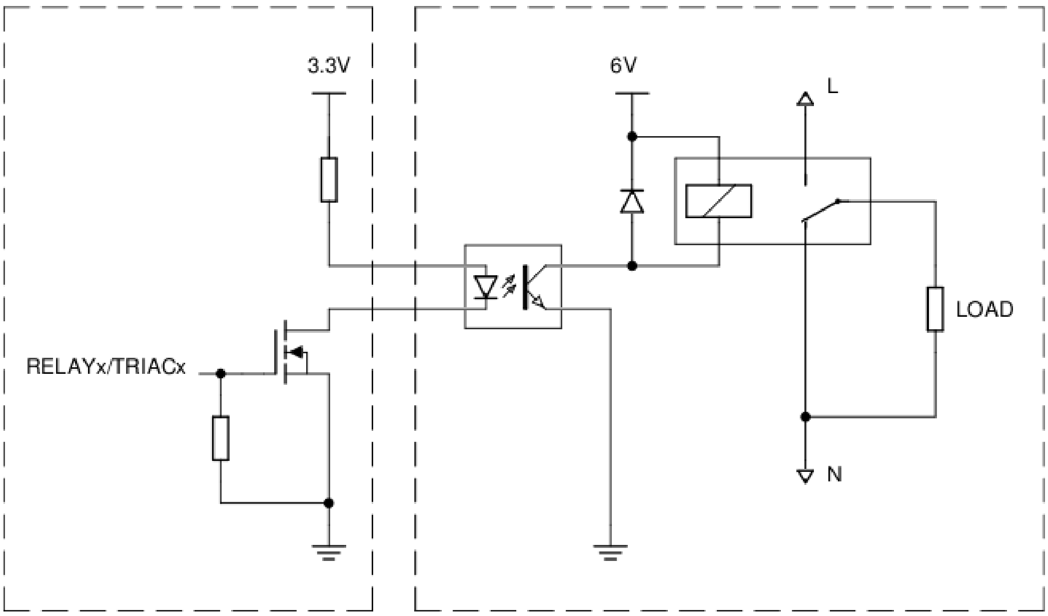


Figure 10.31: Diagram of the Electrical Interface.

The interface consists of five outputs and one input. The output diagram is shown if Figure 10.31. The optocoupler is driven by a MOSFET and the LED current is limited by a resistor. The resistor's value was calculated using the following equation:

$$R = \frac{V_{DD} - V_{LED}}{I_{LED}} = \frac{3.3\text{V} - 1.3\text{V}}{20\text{mA}} = 100\text{R}$$

The forward voltage drop and the forward current for the LED were taken from the datasheet of the optocoupler.

The gate pull-down resistor is there to always keep the MOSFET in a defined state. Without the resistor, the gate would be floating and the transistor could experience undefined behaviour.

On the electrical side, the optocoupler drives either a relay or a TRIAC driver. For more details, refer the previous sections on Electrical (Electronics) Design.

The input circuit consists of only a 10 kΩ pull-up resistor and the line is driven by the open-collector output of the optocoupler. The optocoupler LED is, in this case, driven by an operational amplifier on the electrical board.

10.3.1.4Microcontroller

10.3.1.4.1 Device Selection

It was decided very early that the system should be based around a PIC microcontroller from Microchip Technology Inc. The main reason for this is to give future groups a familiar platform to work with. The project has now been running for three years and, hopefully, it will be taken over by a new group next year. Since all electronics students have been programming PIC microcontrollers in the second year of their course and some of them used PICs for their individual projects, designing a PIC based system was a natural choice.

The next task was to choose a single device from a huge list. Using a Product Selector tool (Microchip Technology Inc.) and parametric search, the list was shortened to only a dozen devices. The list of features, that were considered necessary during the selection, is provided below:

- Large number of input/output pins;
- SPI module;
- I2C module;
- Reasonable amount of program and data memory.

Since all of the remaining chips met the set criteria, the cheapest one, PIC18F66K22, was chosen. Before the selected device was deemed to be suitable for the job, silicon errata had to be checked. Silicon Errata describes the silicon issues (bugs) and anomalies that affect a particular device. Since these issues are not listed in a device's datasheet, inexperienced engineers can find themselves wondering why the device does not work as it should.

There were a number of issues described in the errata, but only one was considered relevant to the project: the built-in analogue-to-digital converter has a flaw that causes high offset errors, high differential non-linearity and other problems. According to the document, the ADC could have an offset of up to 50 LSB. For a 12-bit ADC with 3.3 V reference, $1LSB = \frac{V_{REF}}{2^{12}} = \frac{3.3\text{V}}{4096} = 0.806\text{mV}$, so 50 LSB would then be equal to about 40 mV offset. The errata suggested that the device could be calibrated to compensate for the offset, but it was decided that a low-cost ADC should be used in the temperature measurement circuitry.

Since the PIC18F66K22 cost considerably less than other devices with similar features and no more significant issues were found, it was decided that the microcontroller could be used in the design.

10.3.1.4.2 Clock Source

One of the essential components required for fast and stable operation of a microcontroller is an external clock source. For this purpose, a 16MHz crystal oscillator was used. In order to create stable oscillations at the correct frequency, most crystals require a specific load capacitance. The total load capacitance required is specified in the oscillator's datasheet and is used to calculate values for individual capacitors. [Appendix N: Calculations of Crystal Oscillator Load Capacitance Values] provides the background and equations for finding the capacitor values.

In this case, the crystal required 20pF load capacitance. Assuming a 10pF stray capacitance, the required capacitor values were:

$$C_L = 2 \times 20\text{pF} - 10\text{pF} = 30\text{pF}$$

10.3.1.4.3 Programming and RESET

PIC microcontrollers can be programmed in circuit, using an In-Circuit Serial Programming (ICSP) header. The ICSP header consists of five pins:

1. Master Clear (MCLR);
2. Power;
3. Ground;
4. Programming data (PGD);
5. Programming clock (PGC).

The MCLR line is pulled high with a 10 kΩ resistor. Upon completing programming, the programmer brings MCLR line low and resets the microcontroller. A manual reset function can be implemented by having a push button that connects the MCLR line to ground when pressed.

10.3.1.5 User Interface

10.3.1.5.1 Keypad

The keypad was designed and built as a part of the control system. It is made of four push buttons, four 10 kΩ resistors and a pin header. The schematic diagram is shown in Figure 10.32.

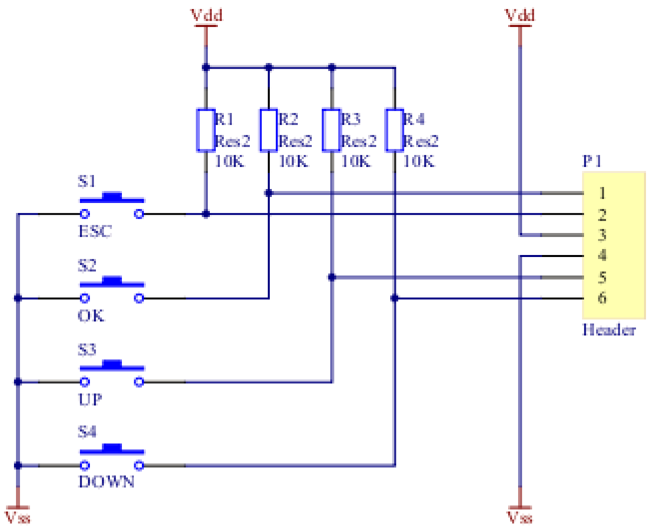


Figure 10.32: Keypad Circuit.

The key signals are all active-low, meaning that they are normally pulled to 3.3 V and are brought to ground level when keys are pressed.

10.3.1.5.2 Display

The control board has an interface for connecting an HD44780-compatible LCD displays. HD44780 is an industry standard dot matrix LCD controller originally developed by Hitachi. There is a wide range of HD44780-compatible alphanumeric displays, starting with 16x1 (16 characters, 1 line) and 8x2 and going up to 40x4.

The board was designed to support a 4-bit interface, as it minimises the number of I/O pins required. LCD contrast can be manually adjusted using a trimmer potentiometer and the backlight is fully software-controllable.

Due to the fact that HD44780 is a rather old controller, it can only run on a 5 V supply. For this reason, the switching regulator was set to output 5 V instead of 3.3 V, which is used by the rest of the control system. Even though the controller requires 5 volts to operate, it can work with 3.3 V level signals without the need for level converters. The LCD controller accepts 3.3 V signal as a valid logic high.

10.3.1.6 Real Time Clock

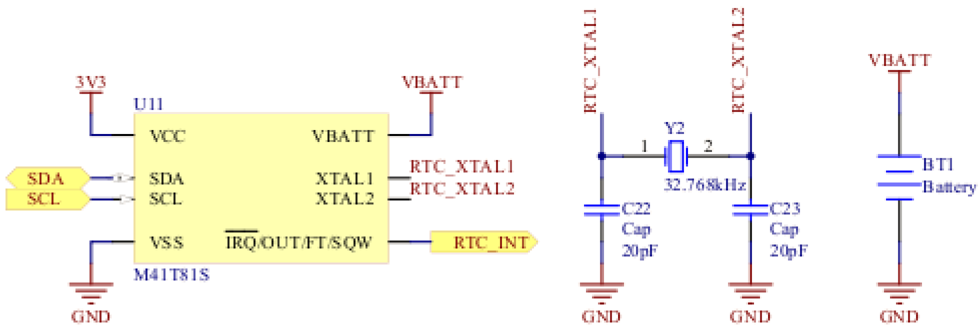


Figure 10.33: Real Time Clock Circuitry.

The control system also has a real time clock (RTC) for time keeping. Some basic timing could be done by using a 100Hz signal from zero-crossing detector, but an RTC is more suitable for extended time measurements as in biofuel production process, which can take over 24 hours to complete. A real time clock also simplifies firmware design and helps save MCU resources for time-critical applications, such as power level control.

The design uses an M41T81S (*Serial access real-time clock with alarms*) from ST Microelectronics. The main features of the M41T81S are listed below:

- I2C serial interface;
- Battery backup mode with typical supply current of 0.6 uA;
- Automatic power switchover;
- Battery low flag;
- Programmable interrupt and alarm function.

The RTC requires an external 32.768 kHz crystal oscillator to operate. The oscillator's datasheet specified a 12.5pF load capacitance, and using equations in [Appendix M: Cold Junction Compensation for K-Type Thermocouples] it was calculated that two 20pF capacitors should be used. In this case, the stray capacitance was assumed to be around 5pF, due to much smaller PCB footprint.

The board also incorporates a battery retainer that accepts standard CR2032 coin cells. The RTC monitors its power supply and automatically switches to battery backup mode in order to preserve the time. When the power is back, RTC will switch from battery. Due to extremely small supply current in backup mode, it was decided that a non-rechargeable battery should be sufficient.

10.3.1.7Micro SD Card Slot

In a control system, such as this, there might be a need for data logging capabilities. Power level to heater temperature relationship, temperature changes over time, process duration – these are just a few pieces of information that could be of interest to a biofuel production system developers or maintainers. In this design, collection and storage of such data is enabled by the presence of a microSD card slot.

The card can communicate with a microcontroller using an SPI interface, which is shared with the ADC. Both the SD card and the ADC have chip select (CS) signals, so there is no need to have separate serial lines.

The card slot has a switch that connects “card in” pin to ground when the card is inserted.

10.3.2 Printed Circuit Board (PCB) Design

Another addition to this year's project was a custom made printed circuit board. There are a number of reasons to design a PCB; some of them are listed below:

- Suitable for medium-to-high complexity designs;
- High integration (number of components per unit area);
- High reliability and quality;
- Better electrical characteristics.

The advantages, compared to cheap prototyping solutions such as stripboards, are numerous and very important. The number of components in this design tops one hundred and prototyping such as system on a stripboard would be tedious and error prone. Moreover, a combination of stripboards and through-hole mounting components could result in an estimated 300% increase in total board area.

When designing a PCB, one has to take into account things like component placement, ways of integrating the board with the rest of the system, signal integrity, manufacturing cost, usability and so on.

10.3.2.1 Layout

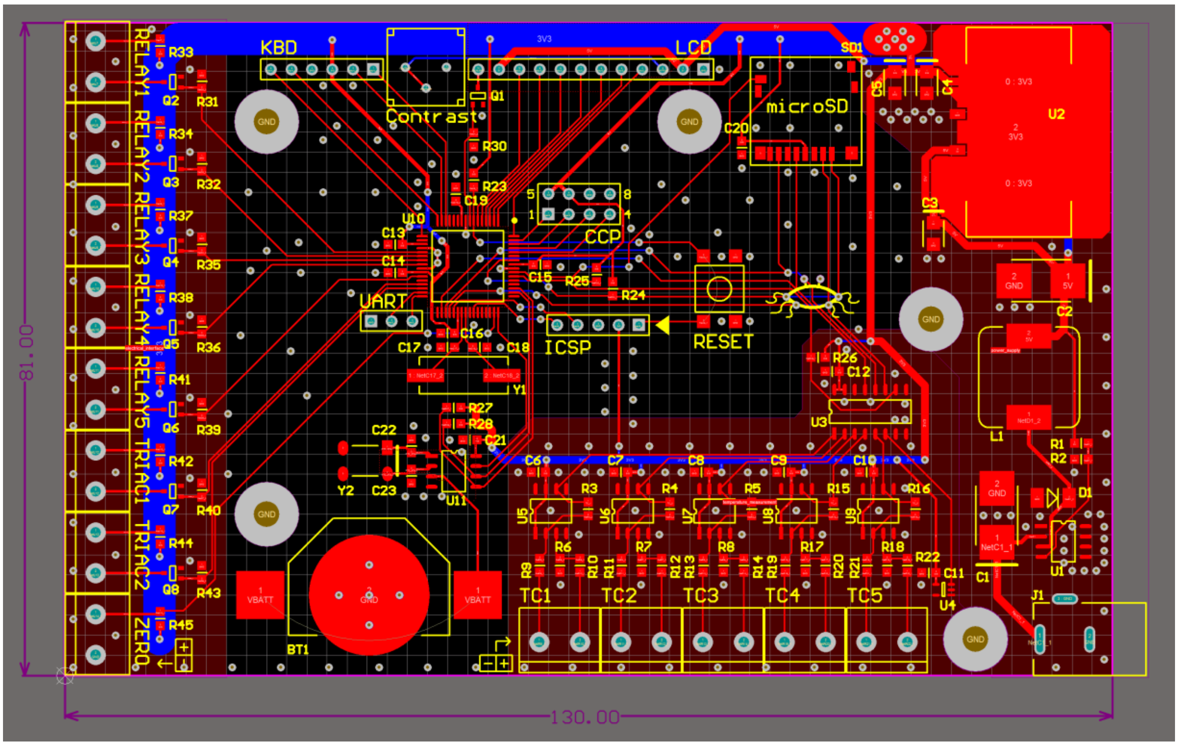


Figure 10.34: Complete PCB Design.

At the beginning of the layout process, the components are arranged in groups. In this design, there were three groups that could be laid out and routed independently: the power supply, the temperature measurement, and the electrical interface. The rest of the components could not have benefited from independent routing and were placed at the later design stages.

Power supply circuitry, located on the right side of the PCB, was one of the first parts to be designed. The datasheet of the buck regulator provided some PCB layout guidance, such as proximity of the components and length of tracks. For the linear part of the power supply, the layout was done considering the power dissipation of the LDO. For this reason, there is a small copper plane under the 3.3V regulator, which connects the device's tab to the heat-sink.

The next step was to lay out the components of the electrical interface, shown on the left side in Figure 9. This group was rather simple to route, as it only consists of some connectors, MOSFETs and resistors, which do not require special treatment. Some care had to be taken when spacing out the terminal blocks, as they are designed to be locked together, as shown in Figure 10.35.

Figure 10.35: Terminal Blocks, sourced from [Rapid Electronics]

The layout for the temperature measurement circuitry (bottom-right on the board) was more complex, but since the most of it consists of five identical sub-circuits (amplification stage), the layout had to be done only once and then repeated. The on-board temperature sensor was supposed to measure junction temperature, so it was placed near one of the terminal blocks.

When the three groups were done, they could be placed on the board. After that was done, the rest of the components could be placed as well. The microcontroller had to go in the middle, as it has connections to all the parts of the circuit. The crystal oscillator was placed near the MCU to get the best performance.

The location for user interface connectors was determined by the position of the LCD and the keypad. Towards the end of the layout, mounting holes were placed in the free space that was not occupied by components or tracks.

10.3.2.2 Other Consideration

One might have noticed that most of the tracks and pads are red. This means that they are located on the top layer of the board. Tracks in blue are on the bottom layer and grey pads are through-hole (i.e. both layers). Having all the components on one layer makes assembly much simpler. Having most of the tracks on one layer (assuming a two-layer board), allows the other layer to be dedicated as a ground plane. Good grounding is essential for signal integrity and EMI performance, therefore having a solid ground plane is highly recommended. From *Design Techniques for EMC* (Armstrong, 2007):

> *A well-designed 0V plane (sometimes called a 'ground plane' or 'RF Reference plane') on its own layer in a PCB is possibly the most cost-effective EMC design technique that has ever existed, or ever will. So it is always recommended to use a 0V plane wherever possible. Trying to reduce BOM costs by removing this plane layer is almost certainly a bad financial decision for the overall project.*

Due to complexity of the design, it was not possible to avoid having tracks on the bottom layer; however, these were kept to a minimum. A four layer PCB would allow to have two signal layers as well as ground and power planes, but it was decided that manufacturing costs are too high to justify for such a medium-complexity board. Instead, free space on the top layer was flooded with copper polygons which are connected to the bottom layer using stitching vias. For clarity, the copper planes are not shown in Figure 10.34.

10.3.2.3 Manufacturing and Assembly

10.3.2.3.1 Keypad PCB

The board for the keypad was home made using copper-clad boards covered in photosensitive etch resist and two types of chemicals: a developer and an etchant.

When the board design is completed, the artwork is printed on a transparency. Using an exposure box, light is shone through the transparency, exposing areas that need to be etched away. After the exposure, the board is dipped in a developer solution, which strips the exposed photo-resist, while leaving the unexposed resist in place. In the final stage, the board is placed in a container with warm ferric chloride solution and the copper, that is not protected by the etch resist, is stripped away.

At this point holes for the pin header were drilled and the components soldered. Figure 10.36 shows an almost complete keypad board.

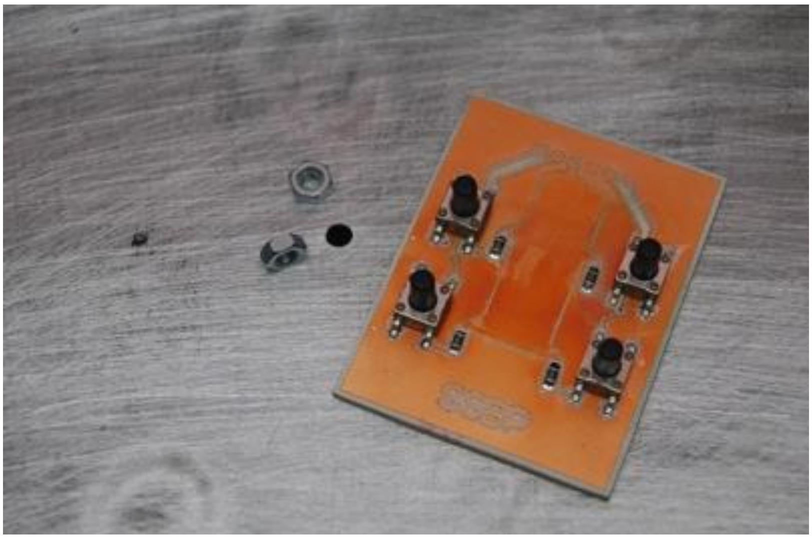


Figure 10.36: Keypad PCB with Surface Mount Components Soldered.

10.3.2.3.2 Control PCB

Control PCB

The manufacturing of the control board was done by a professional PCB manufacturer in China – PCBCart. There are several reasons for having the PCB manufactured professionally:

- Boards can have plated-through holes and vias;
- Solder mask makes it easier to solder fine-pitch components;
- Component markings and labels on silk screen.

When ordering the manufacturing services, one has to provide the specifications for the manufacturing process. Specifications for the control PCB are listed below:

- Board size: 130mm x 81mm
- Material: FR4
- Layers: 2
- Board thickness: 1.6mm
- Copper thickness/weight: 35um/1oz
- Surface finish: ENIG
- Solder mask: Both sides, black
- Silk screen: Both sides, white
- Minimum spacing: 0.2mm
- Minimum annular ring: 0.3mm
- Number of holes: 300-600
- Slots: 3 slots, all plated-through

Altium Designer provides a *PCB information* dialogue for a quick check of the board properties:

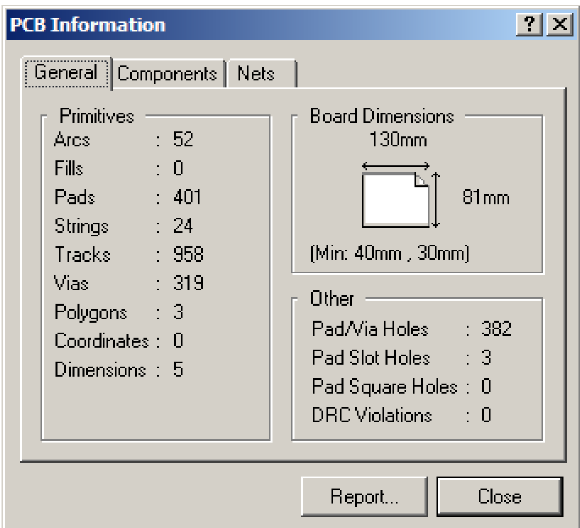


Figure 10.37: PCB Information.

Other properties, such as spacing/tracing and annular ring have to be set in design rules. Lastly, properties such as material, board, and copper thickness, silkscreen and solder resist colours can be provided on fabrication notes.

Before the design files are sent to the manufacturer, it is important to make sure that the design is error free. A good idea is to perform the checks in three different ways:

- PCB layout software, as shown if Figure 10.34. This is the standard view that the designer sees when working on the PCB. Design Rules Check (DRC) **must** be run before generating the manufacturing files.
- 3D view, as shown in Figure 10.38. This view helps spot mistakes that were difficult to see in the layout view, as it gives closer representation of the final product.
- Gerber files check. Gerber files are used for manufacturing the boards. It is highly recommended to check the gerbers to make sure they look as expected.

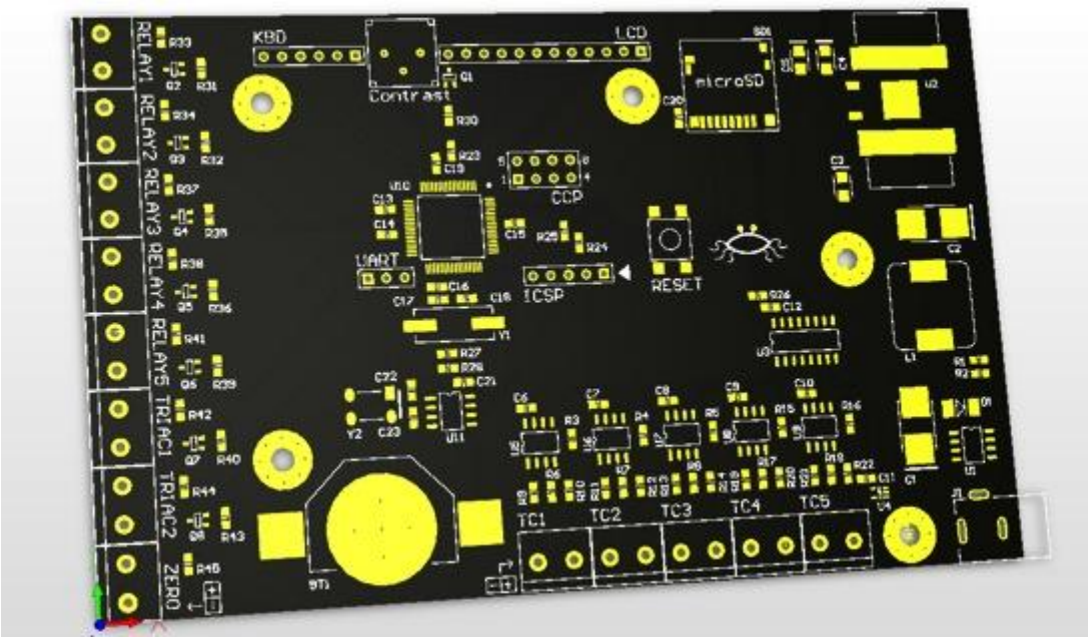


Figure 10.38: Three-Dimensional View of the PCB.

Once all the checks have been done and the design looked good, the files were sent to the manufacturer. To represent the PCB completely, the following files were required:

- GBL – Bottom layer
- GBO – Bottom outline (silk screen)
- GBS – Bottom solder [resist]
- GTL – Top layer
- GTO – Top outline (silk screen)
- GTS – Top solder [resist]
- GTP – Top paste (used for stencil manufacturing)
- GM1 – Mechanical layer 1 (used to mark board size)
- GM2 – Mechanical layer 2 (used for fabrication notes)
- DRL – NC drill file

When the boards were received, they were home assembled using solder paste, a stencil, and a hot air gun. Figure 10.39 shows a fully assembled board.

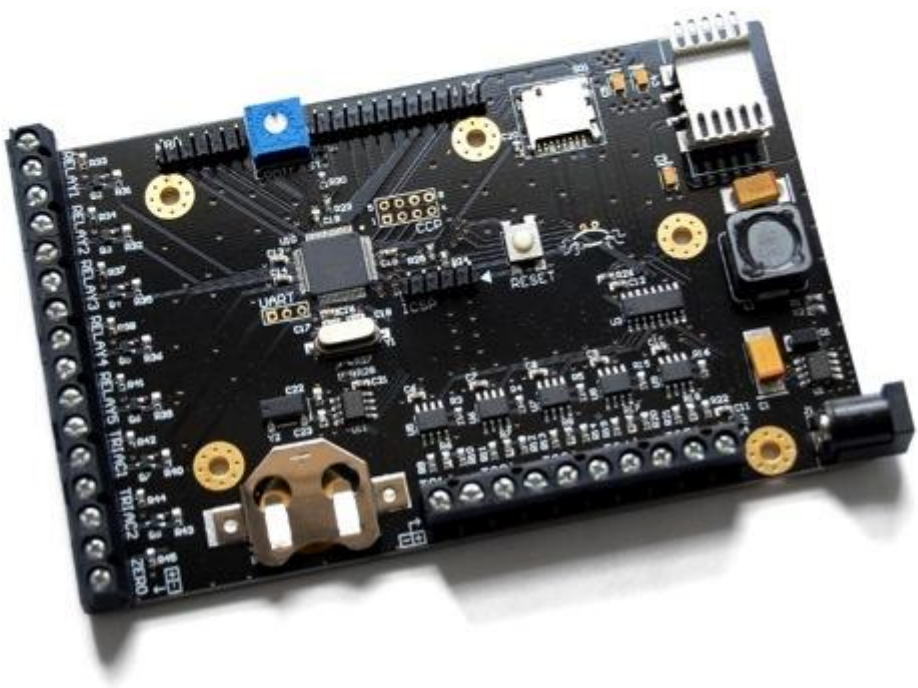


Figure 10.39: Completed Control Board.

10.3.3 Firmware Development

As described in the project proposal, one of the goals was to rewrite the control firmware from scratch. Previous group developed the code in assembly, which is an out-dated language by today's standards. For this reason, a new framework was written in C language, making the code base more much more maintainable.

The following table summarises the core functionality of the framework:

Functionality	Description
LCD control	Enables LCD control using simple commands, such as `lcd_write()`.
Temperature measurement	Implements all the functions required to convert thermocouple voltage to the temperature.
ADC readout	Provides a function for sampling a given channel of the ADC.
SPI configuration	Enables configuration of the SPI bus using a single function.
I/O pin mapping	All the I/O pins are mapped, enabling developers to use meaningful names, such as OK_SWITCH.
Heater power control	Enables simple control of power applied to heaters.
Interrupt function for zero-crossing detection signal	Enables a developer to use a ZCD signal for TRIAC control.

More detailed description of implementation of some of the above functionality is provided in the coming sections.

10.3.3.1 LCD Control

The code was developed to enable simple control of HD44790-compatible LCD displays. The lowest level function for controlling the LCD is `_send_nibble()` which is used to send four bits to the LCD and then clock it.

The `_send_byte()` function executes `_send_nibble()` twice, since the board was designed to use a four-bit mode.

Two slightly higher level functions are `lcd_command()` and `lcd_data()`. These two functions select the appropriate registers before sending a byte to the LCD controller.

The controller has two internal registers: an instruction register (IR) and a data register (DR). The instructions (commands) and addresses are loaded into IR, while data is loaded to DR. The register is selected using a *register select* (RS) pin.

The cursor can be moved by sending the appropriate instruction and the cursor address using a `lcd_command()` function. To display a character in the current location, one can simply use `lcd_data()` function with a wanted character code. For ASCII characters, the function can be used as follows: `lcd_data('A')`.

These are the basic functions that are used to further abstract the LCD control, enabling the developer to display complete strings of characters as well as add custom symbols. For further insight into the LCD controller functionality, refer to the HD44780 datasheet. Capabilities of LCD control code can be examined by looking at the source code.

10.3.3.2 Temperature Measurement

The thermocouple measurement code implements functions and tables listed in [Appendix M: Cold Junction Compensation for K-Type Thermocouples]. The coefficient tables do not contain all 10 coefficients, as the values are probably too small to store in a single precision float variable on an 8-bit microcontroller. Inverse coefficient list stops at 9th value while reference coefficient list contains only three values.

The code also implements a simple `power()` function that raises a float variable to an integer power. This was done in order to save the program memory, which would otherwise be taken by the `math.h` library.

10.3.3.3 ADC Readout

The reading of ADC is done using a single function: `adc_sample()`. This function takes a number of the channel to be sampled and returns a floating point variable representing a voltage in millivolts.

The `adc_sample()` takes care of enabling the ADC, SPI communication and conversion of the digital value to millivolts.

Page 21 of MCP3008 datasheet provides the timing diagram for SPI communication between the ADC and a microcontroller. The details of the implementation can be found in the source code.

10.3.3.4 Heater Control

The heaters are controlled using TRIACs, as they can provide a precise adjustment of power using a phase-fired control technique. This was discussed in Electrical (Electronics) Design section. In this section you will read about the software side of this control mechanism.

In Europe the mains frequency is 50Hz, which means that it takes 20 ms to complete one period. The voltage crosses zero point every half period, resulting in one ZCD pulse every 10ms.

We will assume that the load (heater element) is purely resistive, which is not too far from the truth. The power factor ($\cos \phi$) is therefore equal to one. For a purely resistive load, voltage, and current are in phase, so all the power is real. In other words, no power is returned to the source. Figure 10.40 shows the instantaneous voltage (blue), current (green) and power (red).

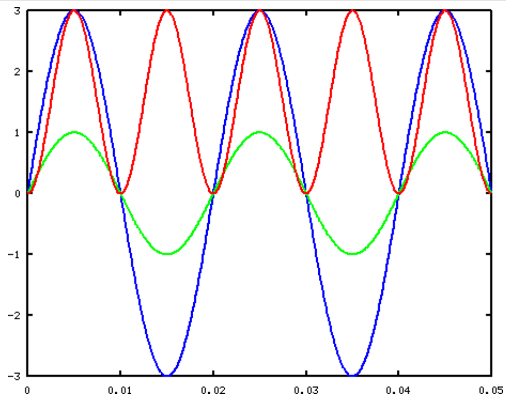


Figure 10.40: Waveforms at Full Power.

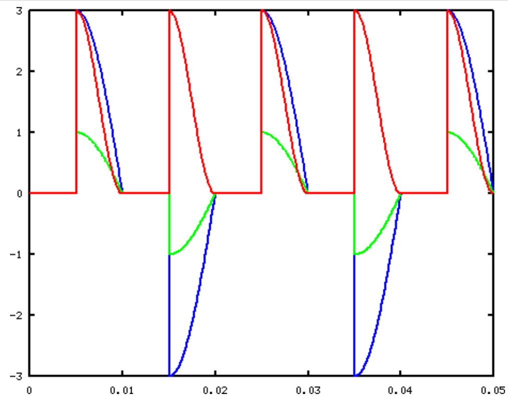


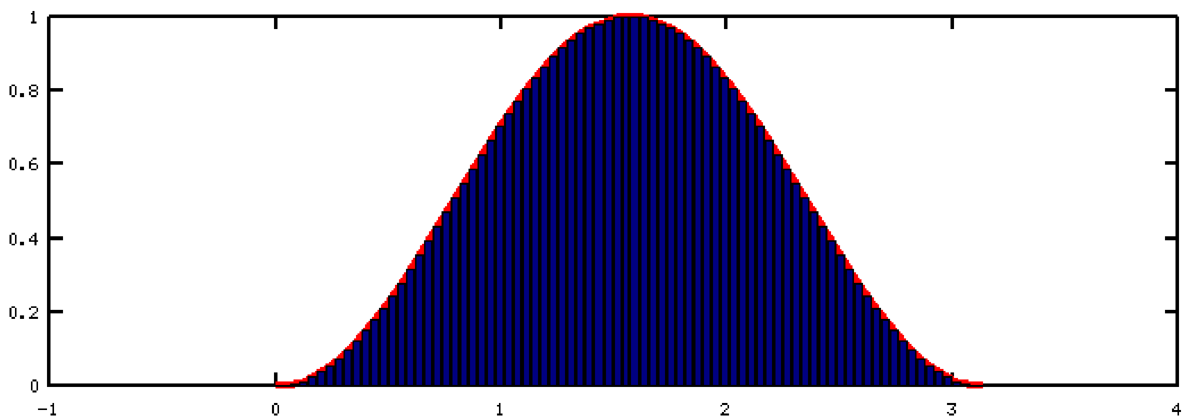
Figure 10.41: Waveforms at Half Power.

To get 50% of the power to the load (Figure 10.41), the TRIAC has to be switched on 5ms after the zero crossing. This information will be used to calculate delays for power levels from 0% to 100% in steps of 10%.

10.3.3.4.1 Construction of Delay Tables

We begin by stating that the power applied to the load is proportional to the area under the red curve, which we can find using integration.

$$P_{1.0} = \int_{0}^{\pi} \sin(x)^2 dx \approx 1.5708$$



Using a MATLAB script, the area under the curve was divided to 100 parts. The lower limit is gradually increased from 0 to 100, the resulting areas calculated and compared to the full area. By inspecting the results, starting points were chosen to give the powers from 90% to 10%. Then these points were converted to delays in milliseconds, as shown below.

$$T_d = \frac{10\text{ms}}{100} x_n \qquad \text{where } x_n \text{ is the starting point.}$$

In order to use the delays on the PIC microcontroller, milliseconds have to be converted to a number of instructions. The PIC runs at 16MHz and has an internal phase-locked loop (PLL) multiplier of x4, giving a total clock speed of 48MHz. One PIC instruction takes four clock cycles to execute, so the resulting rate is $\frac{48\text{MHz}}{4} = 16MIPS$ so in order to get a delay of 2.6ms (90%) at a rate of 16 million instructions per second, the number of instructions required is:

$$2.6\text{ms} \times 16MIPS = 41600$$

X	%	Time (ms)	Instructions
26	90.41	2.6	41 600
34	80.20	3.4	54 400
40	70.25	4.0	64 000
45	60.89	4.5	72 000
50	50.00	5.0	80 000
55	41.05	5.5	96 000
61	29.74	6.1	97 600
67	19.79	6.7	107 200
74	10.65	7.4	118 400

One can see from this table, that the delays require a large number of No-Operation (NOP) instructions. This means that the microcontroller is not doing any useful work during this period. A different approach may be needed to improve efficiency of the code.

10.3.3.5 Control of Biofuel Production

The code discussed above provides the functionality required to develop a program for controlling the whole process of biofuel production. However, due to lack of time, this part was not completed. The planned architecture along with the comments is provided in the [Appendix O: Program Architecture for the Biofuel Production Process].

11 Discussions and Conclusions

Authors: M.A. Haji Md. Said, Y.Q. Yao, C. Obi, & A. Jarušauskas

The subsequent sections within this chapter will focus on the discussions of the design aspects presented in the previous chapter. The discussions will be divided into two main sections the first of which will be focused on discussing the different aspects of the design process that have been presented in the previous chapter. The discussions will then be followed by some general conclusions on the project as a whole, which includes the statements of inability to run the built prototype, some statements on the achievement of objectives and also the statements of departure from the original project proposal.

11.1 Prototype Design

11.1.1 Mechanical and Structural Design

Authors: M.A. Haji Md. Said & Y.Q. Yao

11.1.1.1 Discussion

In terms of the structural design, most of the work that was undertaken by the mechanical team was more of researching and acquiring items and peripherals for the prototype as well as doing some modification to a number of the inherited equipment i.e. rather than doing any fabrication work from scratch. As discussed in the previous chapter, the group basically kept the basics of the prototype design inherited from the previous groups including the use of the macerator, hydrolysis and fermentation vessel, down-pumping impeller, baffle, and the Reflux Still. In doing so, the group could ensure that the limited amount of budget available could be put into acquiring other materials to further improve the design of the prototype. Despite the limited budget that forced the group to reuse as much of the inherited equipment as possible, the group did manage to achieve quite a number of goals set in Table 9-1, albeit only about 60%. Furthermore, when compared to the prototype inherited from the previous group that had undertaken this project, the group do believe that the project is one step closer to achieving the ultimate aim of full system automation.

As mentioned in the previous chapter, taking on one of the recommendations listed by Team 09/10 on reducing the size of the distillation chamber, the group thought it would be best to tackle this issue with acquiring another tea-urn rather than modifying the existing vessel inherited with the prototype that Team 09/10 handed over. This is because upon further inspection, the group found that the vessel had rusted especially on the inside. In addition to that, modifying the vessel would require a specialised work that includes welding which may proove complicated especially on the front of ensuring water tightness. Furthermore the job is also outside the mechanical team's capability, which means that in order to materialise the modification of the existing vessel, the group would need to send the vessel to a specialist welder and it may well prove costly. Hence the group thought the best possible option was to acquire a second tea-urn.

This decision not only would solve the rust problem but also the water tightness issue as it had been designed to contain liquids. Upon discussions within the mechanical design team, a conclusion was made that it was best for the group to acquire another tea-urn exactly the same make as the one inherited from Team 09/10 i.e. the *20 litre Burco Tea-Urn*. The decision was made due to the fact that the mechanical team was familiar with the anatomy of the tea-urn, plus the group was not sure of how much slurry would end up in the distillation chamber, hence it would be risky at the stage of purchase to buy a smaller size (cheaper) tea-urn. Despite the availability of other cheaper options, the team still believes that acquiring the costly (£150) 20 Litre *Burco Tea-Urn* is justifiable. Another reason to support the costly decision was the fact that the group at a later stage of the structural build may well need access to the heating element on the underside of the tea-urn. Based on the inspection of the inherited tea-urn, this is more than possible with the *Burco Tea-Urn*. Furthermore after some research, most of the alternative (cheaper) tea-urn options have purpose-built enclosed heating element, which literally means that the heating element is inaccessible.

However, one of the biggest challenges that the mechanical team faced during the modification work on the tea-urns was the concern on the resulting water tightness of the vessels post-modification. This was especially because most of the modifications were done to the bottom of vessel i.e. drilling holes for pipe connections as well as modifying the damaged heating element of the tea-urn inherited from Team 09/10. This issue was the main concern from the start of the modification processes due to the fact that the underside of the tea-urns houses electrical equipment and a leak could potentially be hazardous. Hence, the modification work was done with close supervision by the technician at the university's student workshop. Any leak issue that the team faced was fixed using an industrial *Plumber's Mait* as well as silicon seal acquired from a local (Brighton) DIY store.

Implementing the idea of utilising the 'free' energy i.e. the earth's gravitational pull was not at all too difficult. With the suggestion of the project's main supervisor, a domestic flat-packed shelving unit was acquired and used as the main frame of the prototype design. The first challenge however was on the task of deciding the size of the shelving unit to be acquired, especially the height. This challenge was overcome by considering the dimensions of the equipment that would be fitted onto the shelves i.e. the macerator, tea-urns and reflux still. Upon acquiring a suitable shelving unit, the group face another challenge on the task of aligning the different equipment on the shelves, which dictated how the wood-shelving panels needed to be modified. The mechanical team managed to overcome this issue (again) by utilising the knowledge of the dimensions of the different equipment as well as by utilising the flexibility of the shelving unit i.e. the fact that the height of each shelves is adjustable.

The final challenges faced by the mechanical team were the issues on interconnecting all of the prototype components using the domestic plumbing pipes and the challenge on connecting the only mains water supply to the equipment that requires the supply of water. With suggestions from the technician at the student workshop, the plumbing issues were overcome doing the measuring, cutting, and fitting work in-situ upon the construction of the prototype. In terms of tackling the issues of splitting the mains water supply, the mechanical team thought it would be best to utilise the unused garden hosepipes inherited from the previous groups. Upon researching the solutions, the team thought it best to make use of the *Hozelock* purpose-designed connectors to split the mains water supply and connect it to all of the equipment. This was another costly decision that the mechanical team had to make, which the team thought was another justifiable expense. This is because all of the acquired *Hozelock* connectors are purpose-designed and –built, hence if used correctly there should not be any concern on the issues of water leaks. Furthermore, due to the limited amount of time available to finish the construction of the prototype, the justifiability of the decision was upheld because the team did not have to worry about redesigning the water supply connection if leaks were found. Reasons being, upon completion of the prototype construction, all that was left for the team to test was that all the connections were fitted correctly i.e. by running the mains water supply and checking for any leaks, which (as expected) there was none.

11.1.1.2 Conclusion

In conclusion, the group did manage to achieve at least three of the five aims set for the mechanical system as summarised in Table 9-1, including the utilisation of the 'free' energy, maximising the space usage as well as the implementation of a filtration (despite it being rather crude and primitive). The group was not able to implement any design changes to either the Reflux Still or the impeller system mainly due to budget and time constraints. This was due to the otherwise unforeseen expenses made on improving the inherited prototype, especially on the plumbing aspects.

The group did manage to complete the construction of the prototype and also managed to prove that the system is water tight, despite the fact that the group was not able to run the system due to some unforeseen health and safety compliance issues, which will be discussed in greater detail towards the end of the chapter on the section titled 'Statement of Inability to Run the Built Prototype'. This will undoubtedly be utilised as the mainframe of any recommendations for future work to be done on the prototype.

11.1.2 Electrical (Electronics) System

Authors: C Obi

11.1.2.1 Results

Before implementing the designed electrical and electronics control system (and due to time constraints), it was first tested by the technician at the student workshop especially on the safety aspects of the design, which was done by checking for proper earth bonding. Upon satisfaction, the design was passed and awarded a temporary electrical safety sticker, which notifies the electrical, electronics and control team that it needs to be retested after a month.

Despite not being able to fully equip (and run) the prototype with all the electrical and electronics control system, a couple of tests were run to test that the electrical and electronic control system were in good working order. A residual current device (RCD) was used (as a safety precaution due to the fact that the system was designed to be connected to the mains power supply) to run testing procedures. Two RCDs were utilised during the testing procedure where one was connected to the 'power in' plug for the TRIACs circuit, whilst the other was connected to the plug for the high voltage PCB, before the RCDs were themselves connected to the mains power supply socket in the workshop.

To show that the electrical system and the control units were working as expected, tests were carried out in the workshop with a close supervision of the project's main supervisor and a technician who works at the workshop. The first test was run to show that the TRIACs configuration and control signal from the control units were working. This was done using a table lamp, where the intensity of the light was controlled by the signal from the control unit. In addition to that the test also utilised a thermocouple that was connected to the microcontroller, which utilised the temperature conditions to send out a signal that would trigger the TRIAC switching it 'on' and 'off' and this in return controls the table lamp. The temperature at the sensing end of the thermocouple was varied using a solder iron and was compared to a set temperature that was programmed onto the microcontroller. Upon sensing a drop in temperature (i.e. when the iron solder was drawn away from the thermocouple sensor), the microcontroller was triggered increasing the power provided to the table lamp, which in return increases the intensity of the light, which technically means that the temperature was maintained at the desired level. This proves that the control system is working as expected.

In addition to the previous test, due to the fact that the heaters used in the prototype built for the biofuel production have the power ratings of 1.5 kW and 3 kW, a fan heater with a variable power imitate these ratings was used to check that the system can safely serve the loads. Upon completion of the tests, a satisfactory observation was made thus it was concluded that the designed system is able power the heaters effectively.

In the previous tests only one socket (i.e. one TRIAC network) was used at a time, so a final test was designed to test both the TRIAC sockets together. This test was done using water heating element, a glass container, and a thermometer. The control system (temperature control) setup was similar to the one used previously, however the only difference is in the physical arrangement where the thermocouple was attached to the side of the glass container. Upon running the test, the water temperature was brought to 30°C, a point at which the temperature control system is triggered and the power to the heater was cut. As the temperature drops below the set point, the microcontroller triggers a different signal that sets the power to 50% to slowly warm up the liquid and the cycle continues to regulate and maintain the temperature at the desired level. After a set amount of time based on the microcontroller program setup, the second stage was triggered where second TRIAC is then used to bring water temperature to 78°C. A similar temperature control technique (of regulating the temperature of the water) to that of the previous stage was used. Upon completion of the tests it was concluded that the control system design was a success as the temperatures on both stages are well maintained to within a ±2°C errors.

11.1.2.2 Discussion

The electrical and electronics system designed by the group for this production can be considered to be advancement from the work done by the previous groups. As mentioned time and time again, the group set out on the project with an objective to make an automated system and so far with the success in the testing procedures, the completion of in the build of the electrical and electronics control systems can be considered to be another goal achievement.

As discussed in the previous chapter, the designed electrical and electronics control system involved the usage of the components such as optocouplers, relays, TRIACs, and TRIAC drivers to control the functionality of the equipment to be used in the biofuel production system such as the heaters, solenoid valves, impeller motor as well as the macerator. At this point it is perhaps worth mentioning that despite both the electrical and electronics control system unit and the process control system unit are interconnected, the two units are electrically isolated with the use of optocouplers. The optocouplers are also the point by which the microcontroller and the electrical and electronics control systems communicate.

During the duration of constructing the electrical and electronics control system unit, some changes were made to the design as and when the need arose. For example, while testing the 9 V relays (under no-load condition) a 5 V supply was used instead and was proven and to be sufficient to switch the relay. Thus the design was altered implementing the usage of the 5 V to supply to the power to the low voltage PCB. However, after the all of components had been put together the 5 V was in fact insufficient, which triggers the need for another change. A simple test was done using a power supply unit (PSU) available at the workshop and it was found that a 6 V supply was sufficient enough to power the relay; hence changes were made accordingly to incorporate the new 6 V supply into the system.

While running the tests on the performance of electrical and electronics control system using a table lamp, the team observed the occurrence of flickering on the light bulb of the table lamp. This was was thought to be an effect of the temperature measurement system.

The temperature measurement system involves a serial communication between the ADC and floating-point arithmetic, which are relatively slow processes. When controlling the heaters, the temperature is measured with every hundredth pulse from the ZCD (i.e. every second), which means that the next pulse is inevitably missed. Hence, this causes the noticeable flicker when operated to drive the power to lamp. This however has no significant effects to the heaters, because the time constant of the heater is large enough that a loss of one AC cycle is insignificant.

11.1.2.3 Conclusion

In the preceding chapter and sections, the designs, test results and discussions of the electrical and electronics control system were been presented. It has been shown that a microcontroller is essential if an automated system is to be achieved. A PIC microcontroller (PIC18F66K22), together with some auxiliary components were chosen and implemented in the design for the reasons that have been addressed in the previous chapter and sections.

Optocouplers were used as the connection hub between the system control units and the electrical and electronics system, which also create electrical isolation between the two systems. The electrical components of the system, such as the solenoid valves and impeller motor, are connected to one side of the optocouplers via using relays that provide the switching ('on' and 'off') control, whereas the TRIACs are connected on the same side as the other electrical components using the TRIAC Drivers. The TRIACs in return are used to precisely control the power supplied to the electrical heaters (that are plugged into it) that are used within the prototype.

Based on the tests done on the electrical and electronics control system units, the group concluded that the objectives were met to an extent. Despite not being able to achieve as much of the originally envisioned aims and objectives due to time constraints, the electrical, electronics and control system team believes that the designed system is more than ready for future groups of student (who chose to undertake the project) to carry on developing the system. This therefore justifies the group's decision to consider this aspect of the project a success, despite not being able to do a test run on the prototype.

11.1.3 Process Control (Electronics) System

Author: A. Jarušauskas

11.1.3.1 Discussion

In the preceding chapter the design of the control system have been presented. A set of aims and objectives was set based on the analysis and observations made on the state of the inherited prototype. System re-usability and cost-effectiveness were some of the main focus points of this project. The first issue was addressed by creating a printed circuit board (PCB) based design with neat wiring and assembly with full schematic diagrams and hardware documentations. The control program code has been rewritten in C programming language, making it much more readable and maintainable. The cost issue was addressed by careful circuit design and component selection. The total spending on the electrical and electronic subsystem was similar to expenses of the previous group i.e. Team 09/10 (which is about £340 in total), although despite having similar budgeting the group managed to produce a much more advanced design.

Regardless of the great overall result on the design of the control system, there were still some issues and compromises had to be made. These will be discussed in the subsequent paragraphs.

Due to silicon issues, the ADC of the PIC microcontroller was subject to high offset errors. This problem was overcome by designing-in an external 10-bit ADC chip. The silicon errata for PIC18F66K22 state that the internal ADC could be calibrated to compensate for the offset. This solution may have been better in the long term as the design would not have to be updated when devices without the ADC issue become available.

During the testing of the temperature measurement circuit, it was found that the readings were jumping randomly from 20°C to 400°C and more. By inspecting the output of the amplifiers, a large amount of noise was observed. The noise level was reduced significantly by grounding the negative terminals of all thermocouples, making the measurements usable. This problem might have been caused by a thermocouple acting as an antenna and picking up emissions from the switch-mode power supply circuit.

Despite completing the construction of the prototype and the electrical and electronics control boards, the firmware aspects of the project side needs some more work in order to be able to run tests on the prototype. The major shortcoming for the firmware development aspect is the absence of the process scenario implementation. This means that sequence of events and their duration have not be written, let alone tested and adjusted. Most of the development time was dedicated to produce a small framework that will allow easy use of the hardware features available. Functions that are essential for the biofuel production process were given higher priority than “additional” features. The firmware currently supports temperature measurement, electrical interface, and user interface circuits. At this point in time the framework has no code for interfacing to real time clock and SD card at this time.

11.1.3.2 Conclusion

Even though the time did not permit the full accomplishment of the process control system as originally envisioned, the electrical and control systems are more than ready for future groups to work on. Given that the main goal from the start was to redesign the inherited control system hardware and firmware, it can be concluded that this partr of the project was a success.

11.2 Overall Conclusions

11.2.1 Statement of Inability to Run the Built Prototype

Author: M.A. Haji Md. Said

The main aspects behind the group's inability to do a test run on the built prototype were the *'health and safety compliance'* issues. Throughout the prototype construction process, the technicians at the university student workshop (time and time again) reminded the group to ensure that the prototype is safe before deciding to do a test run. In determining the safety of the prototype, the group were advised to contact the university's portable appliance testing (PAT) team to ensure that every element of the prototype (especially concerning the components that requires the supply of the mains power supply) is safe to be used.

Upon completing the construction of the prototype, the project's main supervisor duly invited the university's health and safety officer (HSO) to conduct an inspection on the prototype. Unfortunately, the prototype was not given a green light as the HSO found quite a few aspects of the prototype to be unsatisfactory (summary of the findings together with the group's comments can be found in [Appendix P: Safety Issues Comments]). These issues will be used as the framework of the recommendations towards future work to be done on the prototype, which will be handed onto the next group of students who chose to undertake the project.

11.2.2 Departure from Proposed Budget

Author: C. Obi

During the project planning stage, the project budgeting was proposed showing in the worse case scenario of the likely amount of components and equipment that may be required for the project. However, during the execution of the project, changes were inevitably made especially upon further understanding of the biofuel production system. This consequently affects the amount of components required for the construction of the prototype as well as the total expenses endured by the group.

Part	Initial Quantity	Cost (£)	Final (Purchased) Quantity	Cost (£)
Electrical (excluding VAT & delivery charges)				
Heater Element	1 or 2	20	-	-
SCR/TRIAC	1 or 2	10	3	4.59
Relay	1	10	5	4.60
Other Components		40	-	31.42
Electronics (excluding VAT & delivery charges)				
Microprocessor	5	20	3	8.97
Operational Amplifier	5	15	10	11.70
Temperature Sensor (PCB)	5	5	-	-
Thermocouples	5	30	2m (Pack of 6)	11.41
LCD	1	20	1	9.74
Project Enclosure	1 or 2	20	-	-
PCB Manufacturing			1	92.64
Other Components		40		87.27
Electromechanical (excluding VAT & delivery charges)				
Solenoid Valve	4	20	4	46.25
Mechanical				
Pressure Relief Valve	2	10	-	-
Filtration System	1	50	-	-
General Rig Modification & Services		400		353.20
Tea Urn			1	148.63
Total Cost		**710**		**810.69**

Table 11-1: Initial Proposal Budgeting vs. Actual Project Expenses

Table 11-1 presents the summary of the initial budgeting compared side-by-side with the actual amount spent by the group. From the table it can be seen that during project execution, although some of the parts were proven unnecessary and were not purchased, there was some additional components that required and the purchase of which caused an increase in the total amount spent. Considering that the initial budgeting totalled up to £710, it can be said that the group went over budget by £100.69. Although the actual budget allocated by the university for the project was in actual fact only £600, i.e. £150 per student, the project in actual sense went over budget in excess of £200.

Despite managing to make some savings on a number of parts while more money was spent on other parts, this is because their prices were underestimated at the time of the budget proposal. The noticeable cause for the project going over budget would be the tea-urn, which costs almost £150. The group did not anticipate this to be bought and not every member of the group was aware that it was going to be purchased. And considering the amount of money spent on it, proper consultation should have been made with every member of the group prior to the purchase the tea-urn.

However, the group saved money by planning and making the design such that most of the equipment used by the previous groups such as the macerator, motor and impeller, hydrolysis and fermentation chamber as well as all the substances for the biochemical reactions would be used. Since the costs for these would have further increased the money spent by the group.

11.2.3 Conclusions on Achievement of Objectives

Author: M.A. Haji Md. Said

Referring back to the summary of project aims presented in Table 9-1, the group believe that at least 60% of the collective aims have been achieved, with which the group could safely say that the project is more or less a success.

Looking into the finer detail, the electrical, electronics and control system team did manage to achieve almost a 100% of the aim set at the beginning of the project that are within the areas of their expertise. Despite not being able to do run and operate the prototype, they did manage to produce usable control systems, which can quite easily be implemented into the prototype upon further research and development.

The mechanical team, however, only manage to achieve about 60% of the aims that are set within their areas of expertise. The team are proud that they have considerably improved the structural design of the prototype achieving two goals with one solution (i.e. the implementation of the domestic flat-packed shelving unit). Budget and time constraints however mean that the reconsideration of the impeller and Reflux Still design cannot be achieved. However, given that the previous group to undertake the project have manage to successfully run their prototype with the existing design, the group thought that perhaps it would be best to keep the two components as it is especially in order to reduce the unnecessary expenses incurred.

On the other hand, at least 30% of the aims that were set in the areas of optimising the bio-chemical processes were achieved. The group did do a research into alternative methods of pre-treating the feedstock, despite no extra processes were implemented in the final design of the prototype. The failure to execute the other aims that were set in the areas of optimising the bio-chemical processes is another example of it being the casualty of the time constraints.

All in all, the group do believe that once all of the safety issues (presented in [Appendix P: Safety Issues Comments]) are addressed, the group believes that the ultimate aim of fully automating the prototype would have been achieved. Hence it is justifiable that the group concluded the project (to an extent) is a success, despite going terribly over-budget due to some unforeseen expenses.

12 Recommendations

Authors: M.A. Haji Md. Said, A. Jarušauskas, & C Obi

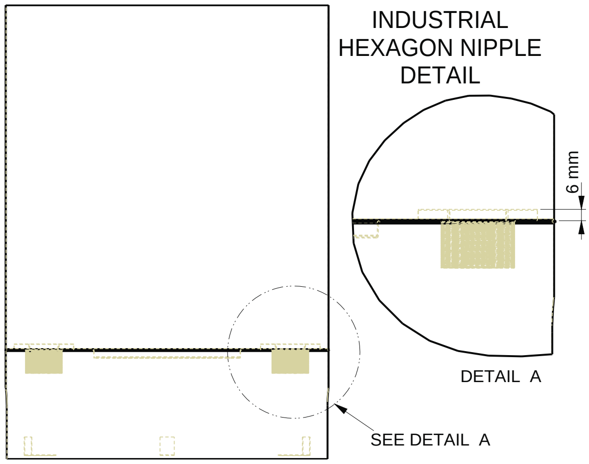
To conclude the report it is perhaps best to lay down some lists on the recommendations for future work and developments on the project, especially if the project were to achieve its ultimate aim of producing a commercially viable small-scale biofuel production system. This final chapter will be divided into four main sections where the recommendations will be focused on the three main aspects of the project development. The first of these will list some recommendations by the mechanical team towards future work and developments to be done onto the general structural build of the prototype. The next two sections will list some recommendations towards further developments of the electrical, electronics, and control system. The final section will conclude the chapter with some suggestion on tackling the budgeting constraint issues.

12.1 General Structural Build

Author: M.A. Haji Md. Said

First and foremost, the main concern on the recommendations towards future work to be done onto the built prototype is to adhere to the health and safety issues listed by the Health and Safety Officer (HSO) which were summarised in [Appendix P: Safety Issues Comments].

In order to achieve total automation perhaps it would be beneficial to automate the control of the industrial ball valves or even implement motorised valves such as the ones used in domestic and industrial plumbing systems.



Secondly, the utilisation of the industrial hexagon nipple means that there is a 6 mm step between the bottom of the vessel and the outlet point of the slurry. This would consequently mean that an amount of material (liquid or slurry) would inevitably be left in the vessel even after the cleaning process was run. Hence it would perhaps be beneficial to find an alternative where the outlet point is flush with the bottom of the vessel. One suggestion would be to utilise domestic plugholes, an example of which is the ones commonly used in domestic household sinks.

Thirdly, it would be of great benefit if a proper waste collecting system were designed. An example of this could include the detachability of the waste collection bin. Otherwise, if at all possible, the prototype could perhaps be connected to the mains waste drains of the premise where it is installed.

Finally in recognition of the health and safety issues listed by the HSO, the wood block used to raise the prototype frame should be changed and perhaps fixed either onto the frame or floor to avoid the possibility of anyone dislodging the block and knocking the prototype over. Other health and safety issues, the future mechanical team should work together with the electrical and electronics team to properly earth-bond the prototype frame, to avoid the possibility of any electrocution.

12.2 Electrical and Electronics System

Author: C Obi

For a more portable system, the utilisation of the 10 V_{AC} power supply unit (PSU) should be reconsidered. An AC source could be obtained in the process of building a low voltage PSU, thus eliminating the need for the socket where the 6 V power supply will be connected to during production process.

Also it would be beneficial if the electrical wirings and connections of the TRIACs could be made a bit tidier by fixing all the connectors in an enclosed plastic box in order to prevent wires slipping out of the connectors and shorting the circuit.

Finally, as the designed system currently utilises three plastic enclosures, it would be more beneficial to attempt to increase the system robustness. This perhaps could be achieved by combining the two printed circuit boards (PCBs), although this may not be possible until after the first recommendations listed in the previous paragraphs have been accomplished.

12.3 Process Control System

Author: A. Jarušauskas

At this point, the main recommendation would be to continue the development of the control firmware. The main control program, such as the one described in [Appendix O: Program Architecture for the Biofuel Production Process], needs to be written in order to run full system tests. The code will then have to be adjusted based on the results and developed further.

Depending on group structure and resources, members could work on improving other aspects of the code, such as structure and efficiency, temperature control algorithm and implementing the currently missing RTC and data logging functionality.

Due to high time constant, the heaters do not require a complex algorithm to keep the temperature at a set point. However, it may still be appropriate to implement a Proportional-Integral-Derivative (PID) temperature control.

12.4 Budget Constraints

Author: M.A. Haji Md. Said

Owing to the fact that the project went significantly over-budget, the group thought it would be best to suggest that future group should look into ways of acquiring extra funding to support the project rather than relying on the funds provided by the university alone. Based on the research done throughout the execution of this project, in addition to Achor International, the group also found that there are quite a number of organisations that supports the development of green technology such as the Waste and Resources Action Programme (WRAP) and the National Industrial Symbiosis Programme (NISP). Hence perhaps it may well be beneficial for the future groups to approach these organisations and ask for sponsorship.

13 References

Abengoa Bioenergy. (n.d.). Retrieved December 10, 2010 from Abengoa Bioenergy Website: http://www.abengoabioenergy.com/corp/web/en/index.html

Abengoa Bioenergy. (n.d.). *Abengoa Bioenergy 2009 Annual Report*. Retrieved December 10, 2010 from http://www.abengoabioenergy.com/corp/export/sites/bioenergy/resources/pdf/acerca_de/en/Annual_report_2009_1.pdf

Achor International Ltd. (2009). *Achor International*. Retrieved October 14, 2010 from Achor International: Next Generation Clean Technology: http://www.achorinternational.com

Armstrong, K. (2007). Design Techniques for EMC - Part 5 PCB Design & Layout.

Asia Biomass Energy Cooperation Promotion Office. (n.d.). *To Expand Domestic Biofuel Production in Japan*. Retrieved December 10, 2010 from http://www.asiabiomass.jp/english/topics/1005_02.html

Awolokun, O., Adams, C., Hambos, T., & Parr, R. (2009). *Waste to Bio Ethanol Project*. M.Eng. Dissertation, University of Sussex, Department of Engineering and Design, Brighton.

B&Q Plc. (2011). *B&Q Website: DIY.com*. Retrieved May 1, 2011 from B&Q Product Pages: http://www.diy.com/

BiogenGreenfinch. (2010). *Anaerobic Digestion in More Detail*. Retrieved January 2, 2011 from BiogenGreenfinch: About Anaerobic Digestion: http://www.biogen.co.uk/over-about-ad.asp

Boylestad, R. L., & Nashelsky, L. (2002). *Electronic deevices and circuit theory*. Prentice Hall.

BP. (n.d.). *Biofuel Projects: Biofuels from Sugarcane*. Retrieved December 10, 2010 from BP Website: http://www.bp.com/sectiongenericarticle.do?categoryId=9030046&contentId=7055176

BP. (n.d.). *Biofuel Projects: Dedicated Energy Crops*. Retrieved December 10, 2010 from BP Website: http://www.bp.com/sectiongenericarticle.do?categoryId=9030047&contentId=7055177

BP. (n.d.). *BP Biofuels: Biofuel for the Future*. Retrieved December 10, 2010 from BP Website: http://www.bp.com/sectiongenericarticle.do?categoryId=9030052&contentId=7055186

BP. (n.d.). *BP Biofuels: BP and Biofuels*. Retrieved December 10, 2010 from BP Web site: http://www.bp.com/sectiongenericarticle.do?categoryId=9030043&contentId=7055171

Bridgwater, E., & Dr. Parfitt, J. (2009). *Evaluation of the WRAP Separate Food Waste Collection Trials.* The Waste and Resources Action Programme (WRAP). Banbury: WRAP.

Chen, G.-Q. (2010). *Plastics from Bacteria: Natural Functions and Applications.* Verlag Berlin Heidelberg : Springer.

Cooley, B. (2005). *SimpleIO - Application Note - Triac Series Gate Resistor.* Retrieved April 27, 2011 from http://www.quicksource.com: http://www.simpleio.com/design/triacout/AppTriacOutGateResistor.asp

Currie, R., Elrick, B., Ioannidi, M., & Nicolson, C. (2002, May). *Renewables in Scotland: Small Scale*. Retrieved January 2, 2011 from University of Strathclyde MSc Course: Renewables in Scotland: http://www.esru.strath.ac.uk/EandE/Web_sites/01-02/RE_info/small_scale.htm

Danielle, M. (2005). *Ethanol's potential: looking beyond corn.* Retrieved 1 14, 2011 from Earth Policy Institute web site: http://www.earth-policy.org/index.php?/plan_b_updates/2005/update49

DEFRA. (2010). *Food 2030.* HM Government (United Kingdom), Department of Environment, Food and Rural Affairs (DEFRA). Department of Environment, Food and Rural Affairs (DEFRA).

DEFRA. (2009). *Food Matters: One Year On.* Department for Environment, Food and Rural Affairs (DEFRA). DEFRA.

Demand Media Inc. (1999-2011). *About the Chemical Makeup of a Potato*. Retrieved 2011 from eHow Health: http://www.ehow.com/about_4613535_chemical-makeup-potato.html

Enerkem. (n.d.). *Enerkem Profile*. Retrieved December 10, 2010 from Enerkem Website: http://www.enerkem.com/en/our-company/profile.html

Enerkem. (n.d.). *Enerkem's Technology*. Retrieved December 10, 2010 from Enerkem Website: http://www.enerkem.com/assets/files/tachnologie/enerkems_technology_eng_lr.pdf

Environment, Food and Rural Affairs Committee. (2005). *Waste Policy and the Landfill Directive.* House of Commons, Environment, Food and Rural Affairs Committee. London: The Stationery Office Ltd.

Environment, Food and Rural Affairs Committee. (2010). *Waste Strategy for England 2007.* House of Commons, Environment, Food and Rural Affairs Committee. London: The Stationery Office Ltd.

Eunomia Research & Consulting. (2010). *Landfill Bans: Feasiility Research.* The Waste and Resources Action Programme (WRAP). Banbury: WRAP.

Fairchild Semiconductor, C. (2003). *AN-3003.pdf(application/pdf Object).* Retrieved April 27, 2011 from www.fairchildsemi.com: http://www.fairchildsemi.com/an/AN/AN-3003.pdf

Felter, H. W., & Lloyd, J. U. (1898). *King's American Dispensatory:Amylum (U. S. P.)—Starch.* Retrieved 10 13, 2010 from Amylum (U. S. P.)—Starch.: http://www.henriettesherbal.com/eclectic/kings/amylum.html

Finne, M. (2001, 9 27). *CO2 Measurements in Breweries and Breweries.* Retrieved 12 2, 2010 from Vaisala News: http://www.vaisala.fr/files/CO2_Measurements_in_Breweries_and_Wineries.pdf

Hewes, J. (2010). *Relays*. Retrieved April 25, 2011 from The Electronics Club: http://www.kpsec.freeuk.com/components/relay.htm

History of Biofuels - BioFuel Information. (2010). Retrieved 1 3, 2011 from Biofuel.org.uk website: http://biofuel.org.uk/history-of-biofuels.html

Horowitz, P. (1989). *The art of electronics.* WInfield Hill.

Horowitz, P., & Hill, W. (1989). *The Art of Electronics.* Cambridge University Press.

Hoult, D. (2010). *The Open Door Web Site : Technology : Electronics : Optically Isolated .* Retrieved April 20, 2011 from The Open Door Web Site: http://www.saburchill.com/tech/electronics/elect036.html

Incopera, F. P., Dewitt, D. P., Bergman, T. L., & Lavine, A. S. (2007). *Fundamentals of Heat and Mass Transfer* (6th Edition ed.). Asia: John Wiley & Sons (Asia) Pte Ltd.

International Synergies Ltd. (2007). *NISP: About NISP*. Retrieved January 2, 2011 from National Industrial Symbiosis Programme (NISP): http://www.nisp.org.uk/about_us_more.aspx

International Synergies Ltd. (2007). *NISP: What is Industrial Symbiosis*. Retrieved January 2, 2011 from The National Industrial Symbiosis Programme (NISP): http://www.nisp.org.uk/article_main.aspx?feedid=whatis&itemid=0

International Synergies Ltd. (2007). *The National Industrial Symbiosis Programme (NISP)*. Retrieved January 2011, 2011 from http://www.nisp.org.uk/

Laxman, S., Lane-Serff, C., Hitchcock, S., Maunsell, P., & Austick, M. (2010). *Small Scale Biofuel Production.* M.Eng. Dissertation, University of Sussex, Department of Engineering and Design, Brighton.

Lee, P., & Willis, P. (2010). *Waste Arisings in the Supply of Food and Drink to Households in the UK.* The Waste and Resource Action Programme (WRAP). Banbury: WRAP.

Lensu, T., & Alakangas, E. (2004). *Small-Scale Electricity Generation from Renewable Energy Sources.* The Network of Organisations for the Promotion of Energy Technologies (OPET Network). Jyväskylä, Finland: VTT Processes .

Long, C. (1999). *Essential Heat Transfer.* Essex: Pearson Education Limited.

Mascia, P. N., Widholm, J., & Scheffran, J. (2010). Volume 66 of Biotechnology in Agriculture and Forestry. *Plant Biotechnology for Sustainable Production of Energy and Co-products* .

Maxim Integrated Products. (n.d.). *Implementing Cold-Junction Compensation in Thermocouple Applications*. Retrieved April 07, 2011 from http://www.maxim-ic.com/app-notes/index.mvp/id/4026

Maxwell, I. (2009). *Managing Sustainable Innovation: The Driver for Global Growth.*

Merrill, R., & Gage, T. (1978). *Energy Primer: Solar, Water, Wind, and Biofuels.* Delta printing.

Micrel Inc. (2008). *1A 2kHz SuperSwitcher Buck Regulator.* From http://www.micrel.com/_PDF/mic4680.pdf

Microchip Technology Inc. (n.d.). *Microcontroller Product Selector*. Retrieved April 07, 2011 from http://www.microchip.com/productselector/MCUProductSelector.html

NEED. (2010). *Secondary Energy Book.* National Energy Education Development Project (NEED). Manassas, VA: The NEED Project.

Nicholas, J. V., & White, D. R. (1994). *Traceable Temperatures: an introduction to temperature measurement and calibration.* John Wiley & Sons Ltd.

NISP West Midlands. (2010). *Case Study: Energy from Pastry Waste.* The National Industrial Symbiosis Programme. Birmingham: International Synergies Ltd.

NISP Yorkshire & Humber. (2010). *Case StudyL Key Stage for School Dinners.* The National Industrial Symbiosis Programme. Birmingham: International Synergies Ltd.

Quested, T., & Johnson, H. (2009). *Household Food and Drink Waste in the UK.* The Waste and Resources Action Programme (WRAP). Banbury: WRAP.

Ratledge, C., & Kristiansen, B. (2001). *Basic biotechnology.* Cambridge University press.

Rogers, G., & Mayhew, Y. (1995). *Thermodynamic and Transport Properties of Fluids* (5th Edition ed.). Oxford: Blackwell Publishing Ltd.

RS Components Ltd. (n.d.). *Brass Steel Lever Ballvalve, 1 1/4in BSPP*. Retrieved May 1, 2011 from RS Online: http://uk.rs-online.com/web/search/searchBrowseAction.html?method=searchProducts&searchTerm=465-4645&x=0&y=0

RS Components Ltd. (n.d.). *Galvanised Hex Nipple, 1-1/4in BSPT M-M*. Retrieved May 1, 2011 from RS Components Online: http://uk.rs-online.com/web/search/searchBrowseAction.html?method=getProduct&R=3251380&cm_vc=av_uk

Scharlemann, J. P., & Laurance, W. F. (2008, February 28). *How Green Are Biofuels?* Retrieved 2011 from Terry Etherton Blog on Biotechnology: http://blogs.das.psu.edu/tetherton/2008/02/28/how-green-are-biofuels/

Schubert, R. (2009). *Future Bioenergy and Sustainable Land Use.*

SEPA. (n.d.). *Biodegradable municipal waste.* Retrieved May 2011, 1 from http://www.sepa.org.uk/waste/waste_data/municipal_waste/biodegradable_municipal_waste.aspx

Soanes, C., & Stevenson, A. (Eds.). (2005). *Oxford Dictionary of English* (2nd Edition ed.). Oxford: Oxford University Press.

St1. (n.d.). *St1: The Company*. Retrieved December 10, 2010 from St1 Website: http://www.st1.eu/index.php?id=2901

Storey, N. (2009). *Electronics: a systems approach.* Pearson Education Ltd.

Worldwatch, I. (2007). *Biofuels for Transport: global potential and implications for sustainable energy and agriculture.* London ; Sterling, VA: Earthscan.

WRAP. (2010). *Food Waste Fuels South Shropshire District Council's Recycling Collection Vehicle.* Banbury: The Waste and Resources Action Programme (WRAP).

WRAP. (2010). *West Devon Borough Council Capitalises on Food Waste Recycling Services.* Banbury: The Waste & Resources Action Programme (WRAP).

WRAP. (2010). *WRAP: About Us - How We Are Governed*. Retrieved December 27, 2010 from WRAP: Material Change for a Better Environment: http://www.wrap.org.uk/wrap_corporate/about_wrap/how_we_are_governed.html

WRAP. (2010). *WRAP: About Us - Our Priorities*. Retrieved December 27, 2010 from WRAP: Material Change for a Better Environment: http://www.wrap.org.uk/wrap_corporate/about_wrap/our_priorities.html

www.nrpw.com/history.html. (n.d.). Retrieved 1 5, 2011

14 Appendices

14.1 Appendix A: Abbreviations, Acronyms and Nomenclatures

c_p	Specific Heat capacity
g	Acceleration due to Gravitational Pull
β	Fluid Buoyancy Term i.e. $\beta = T_{fluid}^{-1}$
E	Energy Loss
h_{in}	Fluid Heat Transfer Coefficient adjacent to the Internal Wall Surface
h_{out}	Fluid Heat Transfer Coefficient adjacent to the External Wall Surface
k	Thermal Conductivity
L	Thickness of Vessel Wall
μ	(Dynamic) Viscosity
Q	Heat Loss
q	Heat Flux
ρ	Density
T_{∞}	Ambient (Room) Air Temperature
T_{in}	Internal (Slurry) Temperature
t	Time
2G	Second Generation
AC	Alternating Current
AD	Anaerobic Digestion
ADC	Analogue-to-Digital Converter
ASCII	American Standard Code for Information Interchange
BMW	Biodegradable Municipal Waste
CHP	Combined Heat Power
CO_2	Carbon Dioxide

CS	Chip Select
DC	Direct Current
DEFRA	Department of Environment, Food, and Rural Affairs
DGS	Distillers-Grains Soluble
DRC	Design Rules Check
EAD	Electronic Design Automation
EFRAC	Environment, Food, and Rural Affairs Committee
ENIG	Electroless Nickel Immersion Gold
GHG	Greenhouse Gas
I2C	Inter-Integrated Circuit [bus]
IC	Integrated Circuit
ICSP	In-Circuit Serial Programming
IDE	Integrated Development Environment
IEC	International Electrotechnical Commission
I/O	Input/Output
LCD	Liquid Crystal Display
LDC-SEV	Louis Dreyfus Commodities – Santelisa Vale
LDO	Low Drop-Out [regulator]
LED	Light Emitting Diode
LSB	Least Significant Bit
MCU	Microcontroller Unit
MIPS	Million Instructions Per Second
MOSFET	Metal-Oxide-Semiconductor Field-Effect Transistor
NISP	The National Industrial Symbiosis Programme
NOP	No Operation (assembly language instruction)

PCB	Printed Circuit Board
PID	Proportional-Integral-Derivative [controller]
PLL	Phase-Locked Loop
PSU	Power Supply Unit
RCD	Residual Current Device
RMS	Root-Mean-square
RTC	Real Time Clock
SPCO	Single Pole Changeover
SPDT	Single Pole Double Throw
SPI	Serial Peripheral Interface [bus]
TFMRC	Thermo-Fluids Mechanics Research Centre
TRIAC	Triode for Alternating Current
UK	United Kingdom
WRAP	Waste and Resource Action Programme
ZCD	Zero-Crossing Detector

14.2 Appendix B: Various Lists

14.2.1 List of Figures

14.2.2 List of Tables

14.2.3 List of Electronic Files on Disc

14.2.3.1 Digital Copy of Reports

WASTE TO BIOETHANOL (2009)

SMALL SCALE BIOFUEL PRODUCTION (2010)

SMALL SCALE BIOFUEL PRODUCTION (2011)

14.2.3.2 Project Files

14.2.3.2.1 Meeting Minute Documentations

8TH OCTOBER 2010 MEETING

12TH OCTOBER 2010 MEETING

18TH OCTOBER 2010 MEETING

26TH OCTOBER 2010 MEETING

5TH NOVEMBER 2011 MEETING

23RD NOVEMBER 2011 MEETING

14.2.3.2.2 Risk Assessment Documentations

RIG CONSTRUCTION RISK ASSESSMENT

14.2.3.2.3 Technical Drawings

1ST VESSEL LID MODIFICATION (CAVITY DESIGN)

TOP SHELF MODIFICATION (INITIAL CAVITY DESIGN)

MIDDLE SHELF MODIFICATION (INITIAL CAVITY DESIGN)

BOTTOM SHELF MODIFICATION (INITIAL CAVITY DESIGN)

FINALISED TOP SHELF MODIFICATION

FINALISED MIDDEL SHELF MODIFICATION

TEA URN MODIFICATION

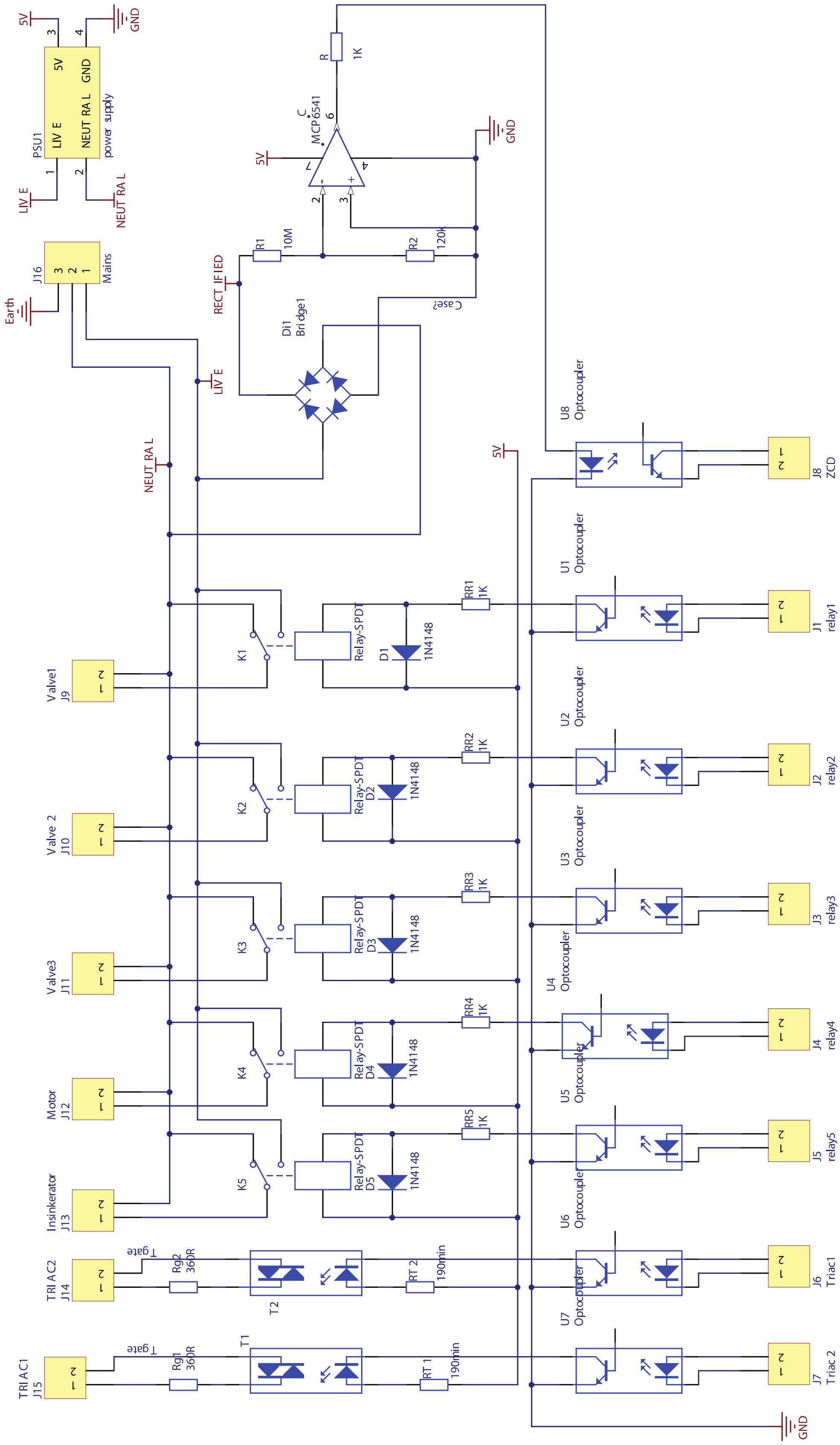
TEA URN LID MODIFICATION (REFLUX STILL BASE)

14.2.3.3 Other Project Documentations and Files

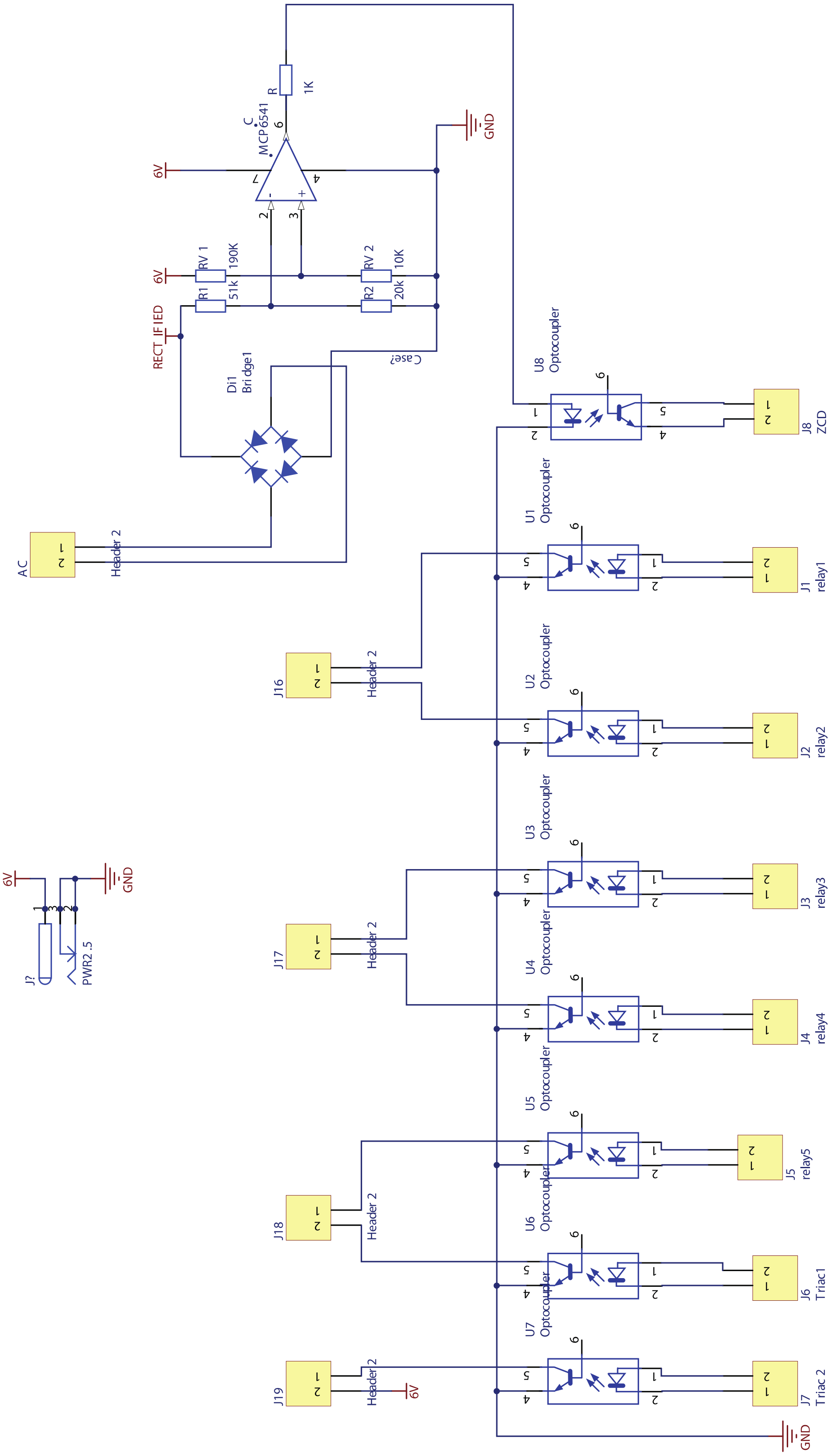
PRO/ENGINEER FILES OF PROTOTYPE MODEL

INSINKERATOR MANUAL

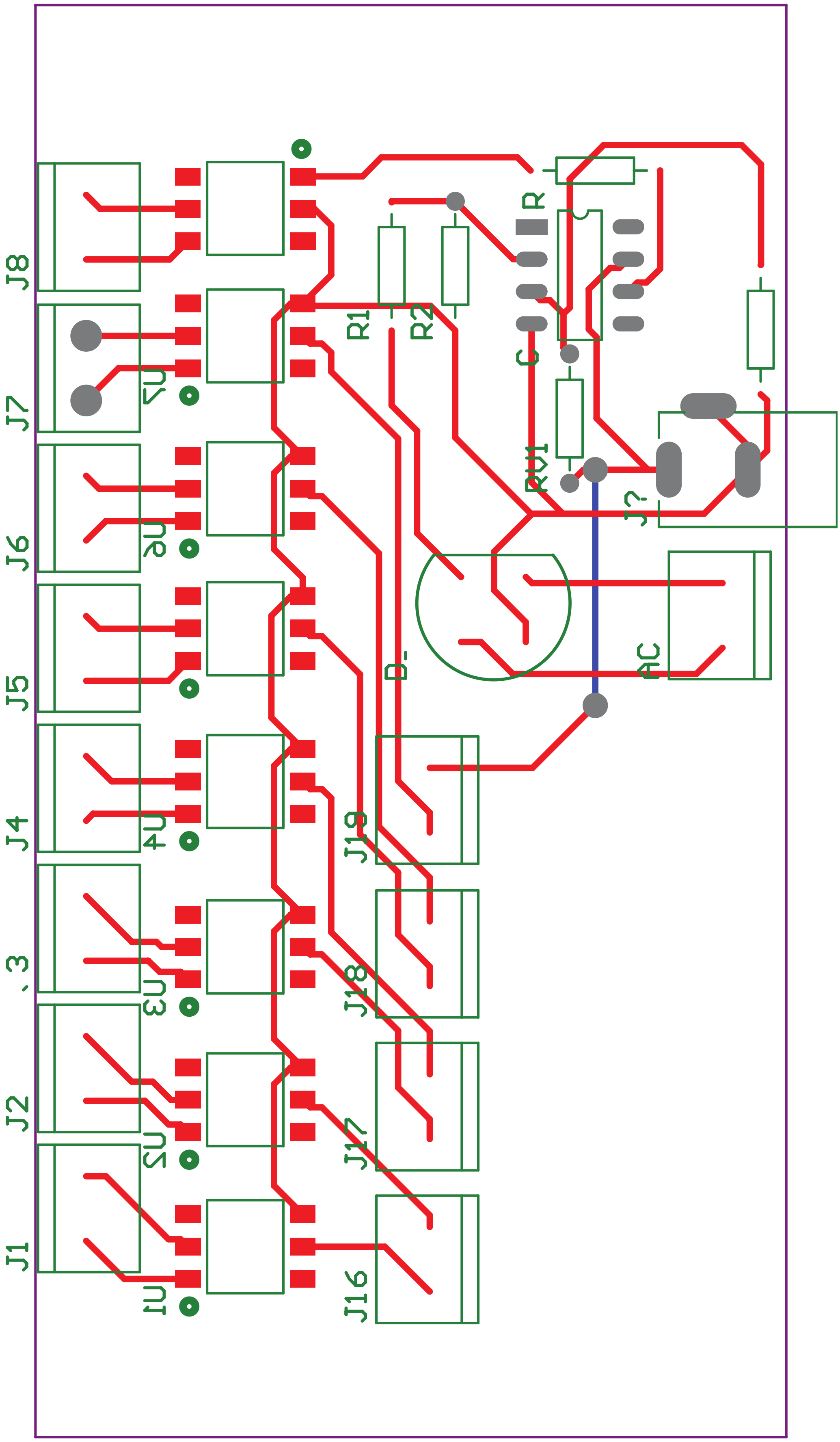
14.3 Appendix D: Schematic Diagram of the Initial Circuit Design



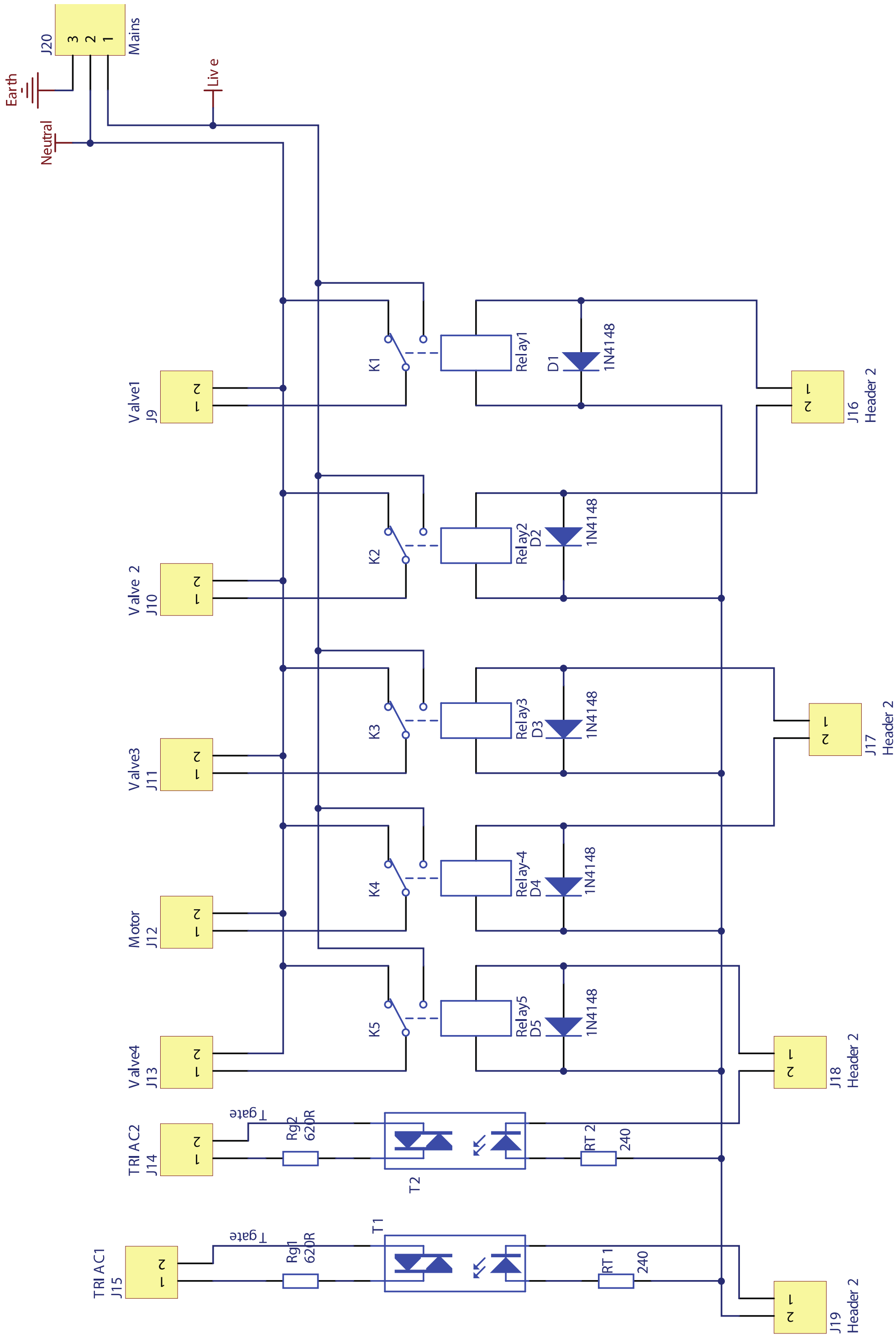
14.4 Appendix E: Schematic Diagram of the Low Voltage Circuit



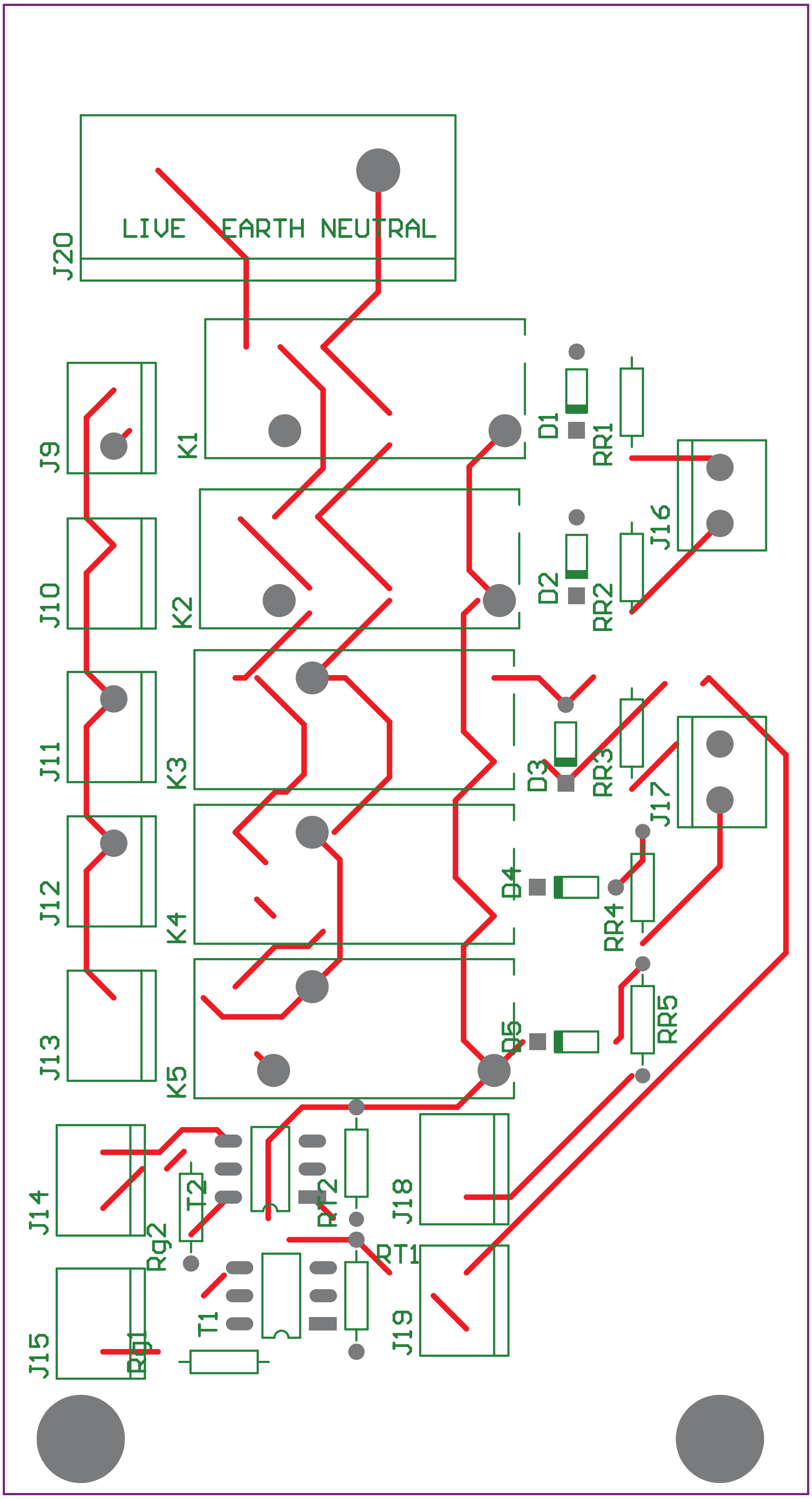
14.5 Appendix F: Low Voltage Circuit PCB Layout



14.6 Appendix G: Schematic Diagram of the High (AC Mains) Voltage Circuit



14.7 Appendix H: High (AC Mains) Voltage PCB Layout



14.8 Appendix I: Thermal Design for TRIAC

14.8.1 Specifications

Maximum junction temperature:	T_{Jmax} = 125°C
Junction-to-ambient thermal resistance:	θ_{JA} = 60°C/W
Junction-to-case thermal resistance:	θ_{JC} = 2.1°C/W
Thermal resistance of the heat-sink:	θ_{HS} = °C/W

14.8.2 Power

On-state RMS current:	I_T = 13A
Maximum power dissipation (from graph):	P ≈ 14.2W

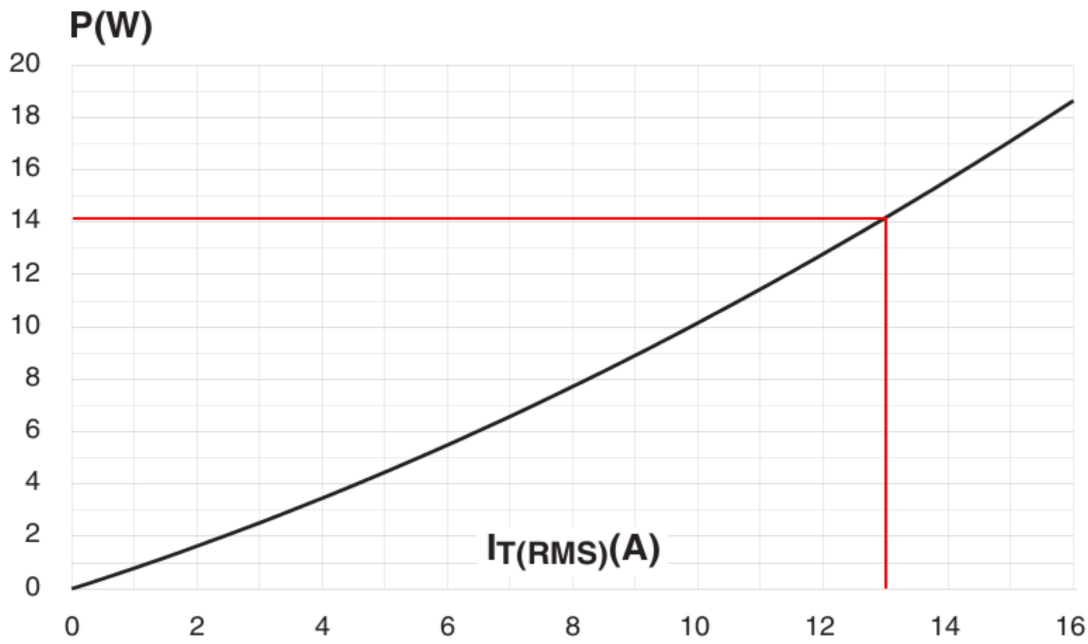


Figure 14.1: Maximum Power Dissipaiton vs. RMS On-State Current (Full Cycle)

14.8.3 Calculations

It is obvious that 14W of power cannot be dissipated by TO-220 package. The calculation below confirms this.

$$T_J = T_A + (\theta_{JA} \times P) = 35°C + (60°\,C/W \times 14.2\text{W}) = 887°C$$

In order to confirm the viability of dissipating the heat with a heat-sink, we need to find the maximum thermal resistance for the heat-sink.

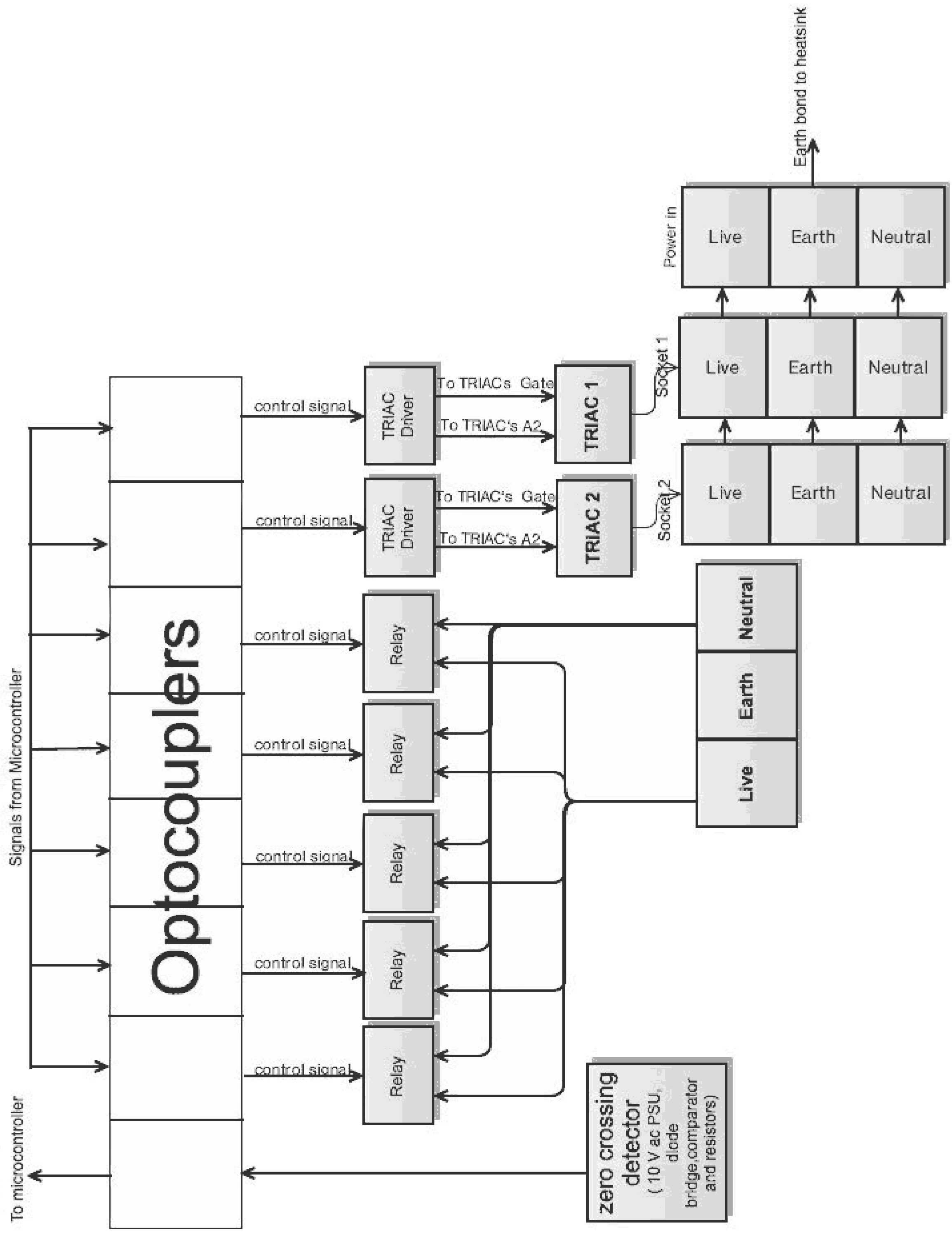
If the maximum ambient temperature is 35°C, then the maximum rise above ambient is:

$$T_R = T_{Jmax} - T_A = 125°C - 35°C = 90°C$$

and the maximum thermal resistance of a suitable heat-sink is:

$$\theta_{HSmax} = \frac{T_R}{P} - \theta_{JA} = \frac{90}{14.2} - 2.1 = 4.2° C/W$$

14.9 Appendix J: Block Diagram of the Whole Design and the Corresponding Signals



14.10 Appendix K: Thermal Design for the MIC4680 Buck Regulator

Author: A. Jarušauskas

14.10.1 Specifications

Maximum junction temperature: T_{Jmax} = 125°C
Junction-to-case thermal resistance: θ_{JC} = 20°C/W

14.10.2 Power

Output: V_{out} = 5V
I_{out} = 1A
P_{out} = 5W

14.10.3 Calculations

Nominal efficiency for a 12V output voltage is given as: η = 70%, therefore, dissipated power is:

$$P_D = \frac{P_{OUT}}{\eta} - P_{OUT} = \frac{5\text{W}}{0.79} - 5\text{W} = 1.33\text{W}$$

The dissipated power is split between the IC and the diode/inductor/capacitor circuit. The datasheet estimates that about 80% of the PD is in the regulator. Therefore,

$$P_{D(IC)} = 0.8 \times P_D = 0.8 \times 1.33 = 1.064\text{W}$$

With this information, we can calculate the worse-case-scenario junction temperature using a formula from the datasheet:

$$T_J = P_{D(IC)} \times \theta_{JC} + (T_C - T_A) + T_{Amax}$$

where T_C is temperature measured at the pins of the IC

T_A is the measured ambient temperature

T_{Amax} is the maximum expected ambient temperature

Therefore,

$$T_J = 1.064 \times 20 + (45 - 25) + 65 = 106.3°C$$

As can be seen from the result, the junction temperature will not reach the maximum even under the worst conditions.

14.10.4 Heat-sinking

The datasheet provides guidance on the size of the ground pad for the converter IC, as shown in Figure 1 and Figure 2. The ground pins of the IC are soldered to a ground plane on the PCB, so the device should not overheat, as suggested by calculations above.

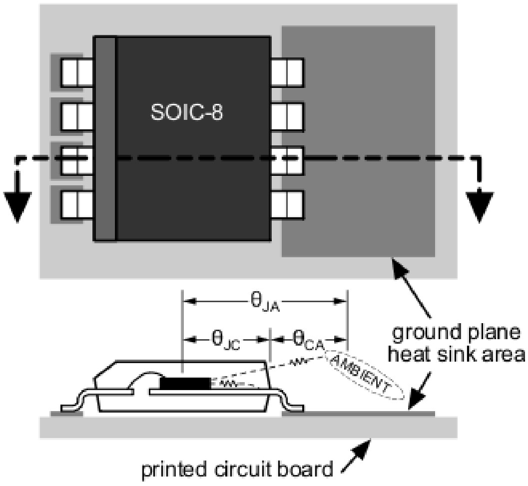


Figure 14.2: Power SOIC-8 Cross Section [1].

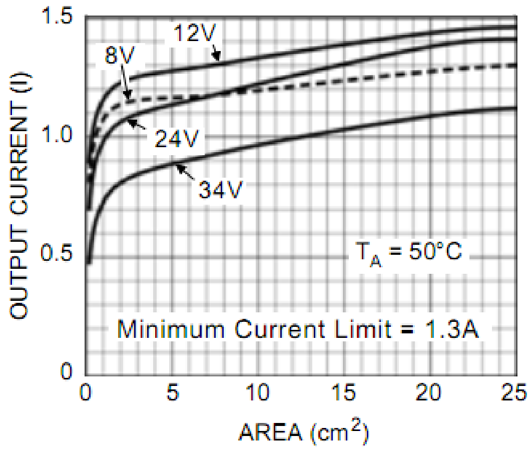


Figure 14.3: Output Current vs. Ground Plane Area [1].

14.10.5 References

1. MIC4680 datasheet. Micrel Inc., 2008.
Available at: www.micrel.com/_PDF/mic4680.pdf
[Accessed: 25 April 2011]

14.11 Appendix L: Thermal Design for the AP1117 LDO

Author: A. Jarušauskas

14.11.1 Specifications

Maximum junction temperature:	$T_{Jmax} = 150°C$
Junction-to-ambient thermal resistance:	$\theta_{JA} = 73°C/W$
Junction-to-case thermal resistance:	$\theta_{JC} = 12°C/W$
Thermal resistance of the heat-sink:	$\theta_{HS} = 25°C/W$

14.11.2 Power

Input voltage:	$V_{IN} = 5V$
Output voltage:	$V_{OUT} = 3.3V$
Input-output differential:	$V_{DIFF} = 1.7V$

The maximum current provided by the wall plug is 1A, therefore:

$$P_{MAX} = V_{DIFF} \times I_{MAX} = 1.7\text{V} \times 1\text{A} = 1.7\text{W}$$

14.11.3 Calculations

Let's start by calculating the resulting junction temperature when no heat-sink is used.

Assuming the full power and 25°C ambient temperature, the junction temperature will be:

$$T_J = T_A + (\theta_{JA} \times P_{MAX}) = 25°C + (73°\,C/W \times 1.7\text{W}) = 149.1°C$$

Clearly, T_J is too close to T_{Jmax}. If ambient temperature is increased to 35°C, for example, then the limit will be exceeded. Therefore, a heat-sink is required.

This time, θ_{JA} will be replaced by (θ_{JC} + θ_{HS}) and we will assume the maximum ambient temperature of 35°C. A good rule of thumb is to add about 30% to the value of the θ_{HS} as the datasheet usually assumes the heat is applied evenly across the surface of the heat-sink [1]. So now we have:

$\theta_{HS'} = \theta_{HS} + (0.3 \times \theta_{HS}) = 33°C/W$
$T_A = 35°C$

$$T_J = T_A + ((\theta_{JC} + \theta_{HS'}) \times P_{MAX})$$

$$T_J = 35°C + ((12°\,C/W + 33°\,C/W) \times 1.7\text{W}) = 111.5°C$$

The new junction temperature is 38°C below the maximum, so the heat-sink should be suitable for the task.

14.11.4 References

1. Electronics Thermal Heatsink Design Tutorial. Jones, D. L., 2010
Available at: http://www.eevblog.com/2010/08/15/eevblog-105-electronics-thermal-heatsink-design-tutorial/
[Accessed: 25 April 2011]

14.12 Appendix M: Cold Junction Compensation for K-Type Thermocouples

Author: A. Jarušauskas

To convert the thermocouple voltage to temperature, an inverse function is used:

$$t_{90} = \sum_{i=0}^{n} d_i E^i$$

where d is an inverse coefficient from the table below
E is the measured voltage in mV

The thermocouple voltage, E, must be compensated for the temperature of the reference junction, therefore

$$E = E_{TC} + E_{REF}$$

E_{REF} is obtained by measuring the temperature of the reference junction using a thermistor. To convert the temperature to electric potential, a reference function is used:

$$E_{REF} = \sum_{i=0}^{n} c_i t_{REF}^i$$

where c is a reference coefficient from the table below
t_{REF} is a measured reference junction temperature

Type K Inverse Function Coefficients	Type K Reference Function Coefficients
d_0 = 0	c_0 = -1.76004136860E-02
d_1 = 2.508355E+01	c_1 = 3.89212049750E-02
d_2 = 7.860106E-02	c_2 = 1.85587700320E-05
d_3 = -2.503131E-01	c_3 = -9.94575928740E-08
d_4 = 8.315270E-02	c_4 = 3.18409457190E-10
d_5 = -1.228034E-02	c_5 = 5.60728448890E-13
d_6 = 9.804036E-04	c_6 = 5.60750590590E-16
d_7 = -4.413030E-05	c_7 = -3.20207200030E-19
d_8 = 1.057734E-06	c_8 = 9.71511471520E-23
d_9 = -1.052755E-08	c_9 = -1.21047212750E-26

Functions and coefficients have been taken from [1].

14.12.1 References

1. NIST ITS-90 Thermocouple Database. NIST., 1990
Available at: http://srdata.nist.gov/its90/download/type_k.tab
[Accessed: 25 April 2011]

14.13 Appendix N: Calculations of Crystal Oscillator Load Capacitance Values

Author: A. Jarušauskas

Most crystal oscillators require load capacitors to operate. The required load capacitance value will be given in the crystal's datasheet. Application note AVR042 [1] from Atmel Corporation provides guidance on choosing the values for individual load capacitors.

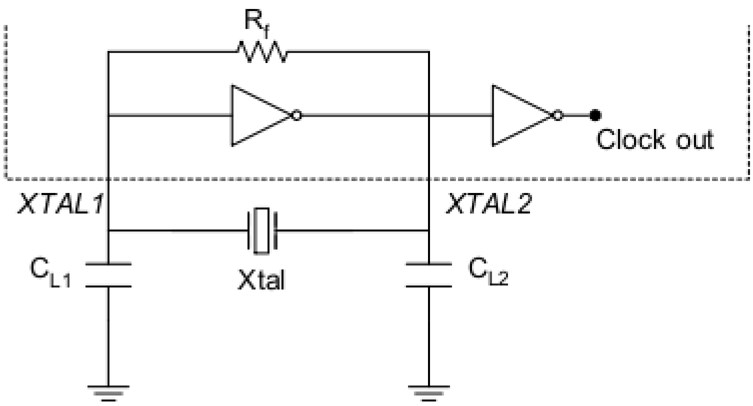


Figure 3 shows a typical crystal oscillator connection diagram. The load capacitors are labelled C_{L1} and C_{L2}. The following equations show the relationship between the total load capacitance seen by the crystal and the individual capacitors:

$$C_{LT} = \frac{C'_{L1} \times C'_{L2}}{C'_{L1} + C'_{L2}}, \begin{matrix} C'_{L1} = C_{L1} + C_{L1Stray} \\ C'_{L2} = C_{L2} + C_{L2Stray} \end{matrix}$$

Here C_{L1} and C_{L2} are external capacitors. C'_{L1} and C'_{L2} take into account any stray capacitance, which can be estimated to be 5-10pF.

For most applications, $C_{L1} = C_{L2} = C_L$ and $C_{L1Stray} = C_{L2Stray} = C_{Stray}$. The equations can then be simplified to

$$C_{LT} = \frac{C'_L}{2}, C'_L = C_L + C_{Stray}$$

and rearranging for C_L gives

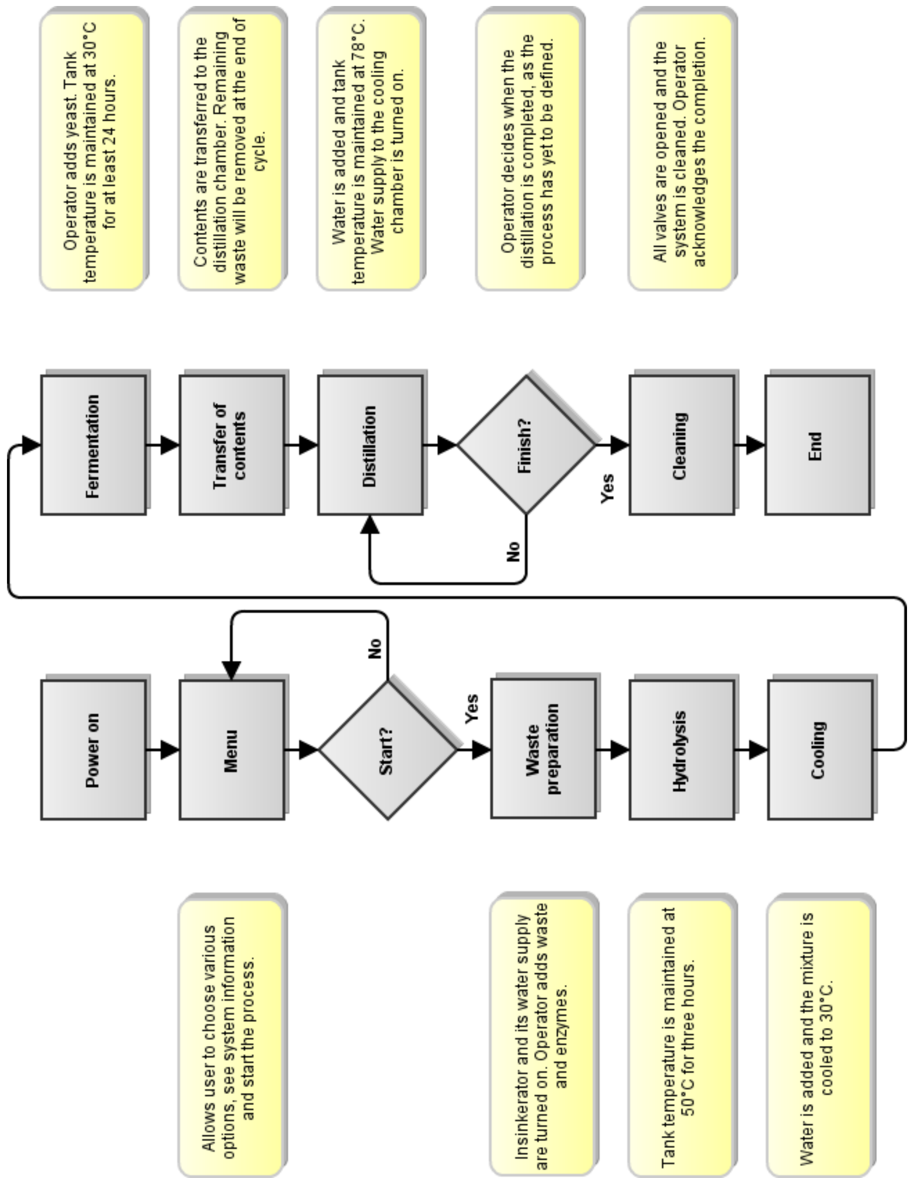
$$C_L = 2 \times C_{LT} - C_{Stray}$$

14.13.1 References

1. AVR Hardware Design Considerations. Atmel Corporation., 2010 Available at: http://www.atmel.com/atmel/acrobat/doc2521.pdf [Accessed: 25 April 2011]

14.14 Appendix O: Program Architecture for the Biofuel Production Process

Author: A. Jarušauskas



14.15 Appendix P: Safety Issues Comments

<table>
<tr><th>Comments from the Safety Officer</th><th>Group comments</th></tr>
<tr><td>Mains heater connections on the fermenter vessel pass through the metal body with no grommets, to an unprotected connection block – this must be rewired with the connection inside the boiler case with a grommet to protect the cable and a cable clamp.</td><td>Action has been taken and the cable is now attached using a strain relief. Earth wire has been attached to the vessel.</td></tr>
<tr><td>Mains operated bare solenoid valves (not yet connected) are unprotected</td><td rowspan="2">The terminals of the solenoid valves are not designed to be protected from ingress of water, nor is such protection practised in the industry. The team, however, recognises that in commercial products these valves are not accessible to the user.

It is, therefore, recommended that all valves be placed in an enclosure, to protect users from electric shock.

The water tightness should be guaranteed by proper attachment of hoses.</td></tr>
<tr><td>Where there is risk of water ingress (most of the 240v connections) the connectors should be to the appropriate IP rating.</td></tr>
<tr><td>All the metal parts including the frame must be earth bonded.</td><td>This should be done as a part of a full system assembly in the future.</td></tr>
<tr><td>All the electrical equipment must be tested for electrical safety before use - the portable appliance test (PAT) - by a competent person. This includes the electronic sensing and control modules.</td><td>This should be done after a full system assembly in the future.</td></tr>
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Comments from the Safety Officer	Group comments
All mains equipment should be RCD protected.	Two RCD adapters were acquired for this purpose. For the final system, however, these may not be appropriate. It is recommended that the future groups look deeper into electrical aspects of the project.
The electrical supply within the room may need testing before use; adjacent trunking covers are very loose and barely attached, there is no dedicated earth, the mains isolator is inaccessible, there are only four switched socket outlets of which one has a faulty switch.	This is outside the scope of the project requirements. Appropriate workspace should be provided by the university.
The top hose feed to the macerator is too short.	No further action was taken to tackle this matter, although the alterations would not be too difficult. A successor group could quite easily fix this matter.
Similarly the pressure relief tubing from the fermenter is too short.	
The ethanol take off tap is not securely fitted and is liable to leak and must be rigidly connected to the condenser.	An attempt to fix this was done, but upon further inspection it may still need more attention.
The shelving material, is not suitable if exposed to water	No further action was taken to tackle these matter, due to time constraints. Therefore future group who wish to undertake the project should make this a priority.
The frame is supported on narrow wooden blocks that could easily be dislodged.	