Improving the Drying Technology at Pacific Can Beijing

A Major Qualifying Project Report

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Abstract

The goal of this project is to assist the Beijing manufacturing facility of Pacific Can in determining a more efficient and economical drying system into the manufacturing process of aluminum cans. We analyzed the current drying process, conducted experiments to determine the feasibility of our proposed alternatives, and created a 3D model of our recommended solution for integration into the current process. Major methods used include engineering design, design of experiment, systems thinking and cost-benefit analysis.

Authorship Statement

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Executive Summary

Pacific Can Ltd. has grown from a startup in 1994 to one of China's leading 2-piece aluminum can manufacturer. Along the way the company has applied innovative improvements to their manufacturing process resulting in great success – now one of the most well-known brands in the Chinese metal packaging industry. In a like manner, in their exploration to further improve their manufacturing operations through innovative solutions, they have identified the drying process of their as having potential for improvement. As a result, the goal of this project is to seek an innovative solution, which would decrease the energy consumption and increase productivity of this process.

The focus of this project is on the drying process as the cans exit the washing process after being molded into shape. Currently, the cans exit the washing process and ride on the conveyor belt for 7.8 seconds to allow excessive water to drop from the cans. Next, they enter an industrial size oven operating at 200 degrees Celsius, which contains the cans for 50 seconds. For a single 330ml can, an average 1-gram of residual water needs to be dried in the oven (average of 2.1 grams for a single 500ml can). Pacific Can believes the operating costs of this process could be lowered through an innovative application. Hence, we aimed to familiarize ourselves with the current drying process as well as other well-known drying processes to gather an arsenal of knowledge in this area.

To be innovative, we must first become knowledgeable of not just the current drying process, but of general drying processes as well. For this reason we performed preliminary research in similar drying processes in manufacturing and other industries. During this time we paid special attention to the use of infrared technology and its application in drying. Additionally, we also familiarized ourselves with the Major Qualifying Project (MQP) previously completed in the summer of 2015 by a group of WPI students, whose work we are continuing and building upon. With our research in and the previous MQP's findings and recommendations for the use of infrared technology, we created objectives as a guide to find an innovative design to achieve the goal of this project.

The team completed the following objectives to meet our goal:

1. Analyze the current process at Pacific Can
2. Analyze previous team's results and recommendations
3. Perform experiments with larger quantity of sample cans
4. Design a SolidWorks model of the improved process

To complete our first objective we visited the Beijing Pacific Can location. There we were able to ask questions regarding the process and get the engineers' thoughts on our ideas as well as the recommendations from the previous MQP group. With the information gathered from the Pacific Can visit, we analyzed the findings and recommendations from the previous MQP; completing our second objective. Afterwards, we continued to work towards our third objective.

Objectives three and four were worked on simultaneously. As previous tests were conducted using only one can, we decided to test the efficiency of using infrared tubes using more cans. This would correlate more to how cans enter the drying process at the manufacturing facility; where a constant flow of hundreds of cans enter. In order to perform such tests we created a simulation we could use to run experiments in a lab setting. Meanwhile, we worked on possible designs for a model that could be used at Pacific Can.

Our fourth objective was to create a 3D model of our intended design using SolidWorks, computer-aided design software. The model was used as a reference for the design of our lab simulation and vice versa. With drafts of our designs in place we ran two separate experiments to test for the two different scenarios where infrared could be implemented into the drying process. Figures 1 and 2 represent the lab experiment simulation and the 3D model, respectively. Both tests were run using a tray of twenty-five 330ml cans that was inserted into the heat containment box (as shown in Figure 1). Then set to dry over two sets of tubes.

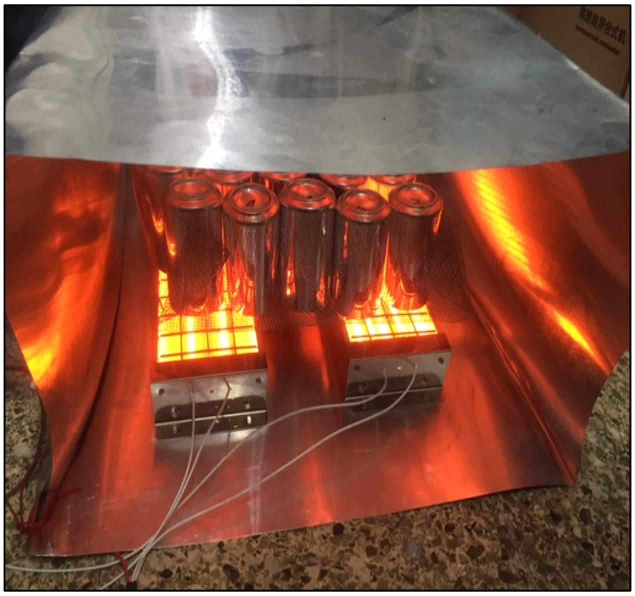

Figure 1: Heat containment box within IR Tube 10cm Apart

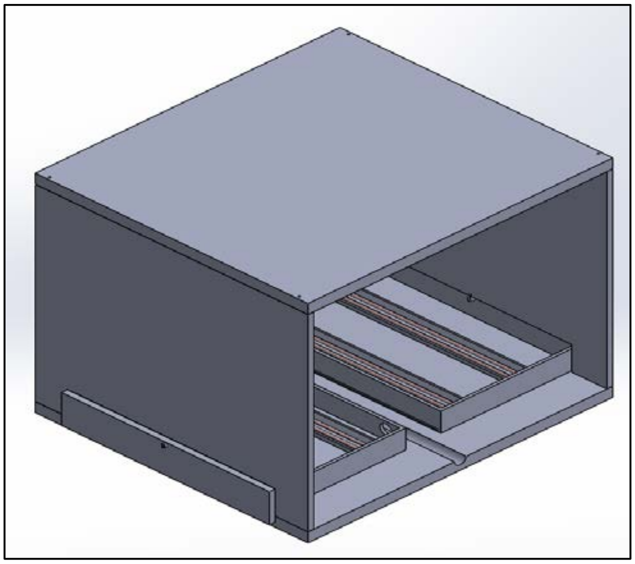

Figure 2: 3D Model of Drying System

The first experiment was a test of how much water evaporated from the can in 10 seconds using infrared tubes. The data gathered during this test would represent the scenario where Pacific Can would implement infrared tubes in the space between the washing process and the current drying oven. Here, the infrared tubes would help raise the temperature of the cans and residual water so the natural gas powered oven does not have to consume as much energy to do so, and bring the water to its boiling point to dry the cans completely.

In the case of the second experiment, we tested for how much water would evaporate in 50 seconds. With this data we analyzed the second scenario – completely replacing the current drying process using infrared tubes. Moreover, further analysis will be conducted to determine the benefits of each scenario.

Results

The date we gathered was positive regarding the infrared tubes' efficiency in drying can quickly. After 10 seconds the cans would be, on average, over 60% dry. Correspondingly, the majority of the cans were completely dry after 50 seconds. We found that there were some discrepancies in our data due to the locations of the can over the infrared tubes. Cans that were directly above the tubes were considerably drier percentage wise than those that were located between the two sets of infrared tubes. Figure 1 shows how the cans would have been placed to dry over the tubes.

Other discrepancies became apparent while conducting the experiments. Firstly, the motion of moving the cans from the station where we added the approximate 1-gram of water to the scale was also a cause for miscalculation. We noticed as the cans were moved in and out of the tray as well as the scale, some water would drop from the cans. Lastly, the method by which we added the 1-gram of water onto the cans was not as precise as we'd hoped. Thus, not all of the cans weighed exactly 1-gram more than they did without the water.

When creating our 3D model, we designed it to fit the first scenario. The short-term goal for Pacific Can is to add the infrared tubes to the existing drying process. This would lower energy consumption by lowering the temperature at which the oven currently operates. An isotropic view of our 3D design is shown in Figure 2. The design would be implemented into the 1.4 m length along which the cans run for 7.8 seconds before entering the drying oven. To encapsulate all of the benefits of using infrared tubes we conducted a cost-benefit analysis (CBA) to get a monetary perspective.

Overall we found that an addition of 4 sets of tubes (as in our 3D design) would lower the operating costs of the current drying process. For our CBA we hypothesized a 25% drop in energy consumption to conduct the calculations. Proportionately, the temperature of the oven would also be lowered by 25%. By doing so we notice a significant amount of savings in operation costs. Furthermore, to gauge profitability in return for investing in the infrared tube addition, we also calculated a Return on Investment (ROI). Using the ROI we found that adding the infrared extension to the current drying process and lowering the energy consumption of the oven by 25%, would result in an ROI of 7%.

Recommendations

After completing the project our team has recommendations for our sponsor Pacific Can. The recommendations for Pacific Can are what our team believes to be the best approach to continuing the project, ultimately implementing the infrared drying system in their manufacturing process. These recommendations include further experiments that the team believes should be done before implementing into the manufacturing system. The following is a list of our recommendations and future work.

- Using the 3D model, create a simulation at Pacific Can to run more accurate tests
- Record temperature of the cans to help determine a lower temperature for the oven
- Run experiments to determine optimal placements for the IR tubes
- Re-calculate a Cost-Benefit Analysis for an up to date return on investment
- Implement waterproof/water resistant infrared tubes to prevent cracking or breaking of the tubes

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1. Introduction

In recent years there has been an increase of research and development in sustainability. Due to the growing concern of climate change and impact of greenhouse gases (GHG), companies like Coca-Cola and Pepsi Co. have pledged to lower their emissions and invest in the research and development of innovative ideas to lower their carbon footprint (Harder, 2015). Such efforts have led to lower operating costs and an increase in profitability and sustainability across the beverage industry. Furthermore, a closer look at the aluminum cans used to package a majority of beverages reveals that there is room for further improvement.

Aluminum cans have become one of the most popular packing methods due to their efficiency and recyclability. In the U.S. alone 95 billion cans were filled in 2013 (Rexam PLC, 2013). As the demand for aluminum cans continues to grow, manufacturers want to reduce production costs and time in order to meet demands. Thus, they have explored innovative solutions to implement into the manufacturing process that can lead to an overall reduction in the energy consumption, cost, and time of the production. One of China's leading aluminum can manufacturing companies, Pacific Can, is seeking to do just that.

Pacific Can is China's leading 2-piece aluminum can manufacturer for beverage packaging. The company has grown from a start-up business to one of the most well-known brands in the Chinese metal packaging industry. Pacific Can has had a great deal of success in implementing an active product-development cycle, leading to numerous innovative solutions. They have identified potential for improvement in the drying process of their aluminum can manufacturing line. They are exploring innovative solutions that can decrease the energy consumption and increase productivity of this process. Therefore, this project will focus on analyzing the current drying process, investigating and experimenting innovative solutions, and provide recommendations for the implementation of our findings.

1.1 Defining the Problem

In the sixth and final cleaning stage of manufacturing, cans are sprayed with a water-based solution in a washer. After cleaning, the cans are dried and then painted. About 2.1 grams (average for 500 ml can) of residual water droplets remain in every can after the cleaning process. When these cans are moved into the oven for drying, due to the residual water in the cans the overall energy consumption imposes a substantial cost in the manufacturing process. In addition, altering the process and reducing the amount of time needed to dry the cans could help increase the amount of cans produced greatly. Through this project, we will look for and implement a solution to improve the overall process such that the amount of residual water droplets in the cans decreases, which in turn will save energy and reduce costs. As a leader looking to remain at the forefront of the can industry, it is essential for Pacific Can to adopt new measures to reduce energy consumption.

The distance between the wash process and the drying oven is about 1.4 meters; this space is the main focus of the team. The goal of this project is to assist Pacific Can in determining and implementing a more efficient and economical drying system into the manufacturing process of aluminum cans. This improvement will help eliminate 2.1 grams of residual water droplets in the cans. It will save the company money and also reduce the amount of energy needed to completely dry the aluminum cans. A previous team of Worcester Polytechnic Institute (WPI) students completed their Major Qualifying Project (MQP) working with Pacific Can earlier during the summer of 2015. In order to make the drying process more efficient, they recommended the integration of infrared tubes to the current process. Our team will be completing more in-depth analysis of this design. The team will then brainstorm improvements and make necessary modifications to the design created by the previous team. The drying system will then be implemented in the Pacific Can facility. The objectives the team will complete to reach the goal are as follows:

(1) Analyze the current process at Pacific Can

(2) Analyze previous team's results and recommendations

(3) Perform experiments with larger quantity of sample cans

(4) Design a SolidWorks model of the improved process

The achievement of our goals and objectives can be measured using statistical methods and the satisfaction level of the company. The team will collect data and complete an analysis of the drying system effectiveness for Pacific Can. The team also hopes to implement the design into the drying process of Pacific Can's facility. The final results and recommendations will be provided to the company. If Pacific Can is pleased with the results of this project and decides to implement the team's design, the goal and objectives will be achieved.

2. Literature Review

Before diving into the essence of our project we reviewed various techniques, skills, and strategies to design our methodology and experiments. Afterwards, we delved into the findings and models reported by the previous MQP team. To build upon their ideas we then researched how infrared technologies are generally used. Knowing how such technology is used in other industries would allow us to be innovative with our solutions. Thus, in this chapter we looked into uses of infrared technology in the aluminum can manufacturing industry as well as other industries.

2.1 Innovation and Entrepreneurship

Innovation is defined as the process through which new ideas are implemented to create value for an organization. An innovative idea must be replicable at an economical cost and must satisfy a specific need. An innovative idea could be the creation of a new system, service, or process, which enhances an existing one by either improving the efficiency of an existing system, service, or process or completely replacing and declaring it inefficient or out-of-date.

The meaning of entrepreneurship is quite elastic. Most would think of it as starting a new business, which would not be wrong. Nonetheless, along the way the meaning of entrepreneurship has expanded. For it is also defined as taking a risk and exploring different opportunities. According to Ajay Bam, a lecturer at University of California Berkeley, “entrepreneurship is the journey of opportunity exploration and risk management to create value for profit and/or social good.” (Brooks, 2015) As starting a new business from the ground up is not the purpose of this project, this definition is more applicable. Instead, we intend to look for other areas where our findings may be applied.

Innovation and entrepreneurship go hand-in-hand; for innovation can be found within entrepreneurship. By itself, innovation would simply remain an idea if not put into action. For instance, Henry Ford is an example of an innovator who followed through with ideas using an entrepreneurial mindset. Indeed, his ideas and vision were very risky. Yet, he managed to get financial backing and convince others to help him carry out his vision; ultimately, leading to the Ford Motor Company. Had his innovative ideas never been followed through entrepreneurially, they would have remained just that – ideas. Therefore, it is our intent to follow through with our ideas and models used to help Pacific Can with an entrepreneurial perspective.

Our intent is to find an innovative idea to improve the drying process of Pacific Can's manufacturing line. Using some of the recommendations from the previous MQP team we will find an innovative solution to decrease energy consumption of the current process. The effectiveness of our solution would be measured by the difference in energy consumption. In monetary terms, this would be done through a Cost Benefit Analysis. Should our innovative solution's expenses – including initial investment, energy consumption, and maintenance costs – be less than those of the current process, it would indeed be an innovative idea. Correspondingly, we will follow through with our idea using an entrepreneurial mindset.

Through entrepreneurship, we can expand our idea to other areas where it can be applied resulting in the same effect. For instance, Pacific Can has many locations throughout China where they could also improve their drying process using our recommendations. This could be further expanded into the aluminum can manufacturing industry and even other industries. By briefly identifying other potential applications for our idea, we would be getting the most out of one idea; which is what it means to be innovative.

2.2 Engineering Concepts

Throughout the course of this project, we utilized various engineering skills and techniques to achieve desired results and outcomes. In this section, we will discuss these concepts and their relevance to different sections of our project.

2.2.1 Engineering Design

According to Accreditation Board for Engineering and Technology, Inc. (ABET), “engineering design is the process of devising a system, component, or process to meet desired needs. It is a decision-making process (often iterative), in which the basic science and mathematics and engineering sciences are applied to convert resources optimally to meet a stated objective” (Haik et al., 2011, 4). Engineering design is the basic problem solving method used by engineers all across the world. It is a systematic method of approaching any problem involving research, innovation, design, experimentation and continuous improvement.

The first step of the process is to identify the problem. In our case, the high costs due to the energy consumption of the drying process. The second step is to research the problem by examining the current processes or state of the issue. Next, the third step involves brainstorming ideas, drawing from math and science theories and skills to base your solution, and then making a 2D/3D model of the proposed solution. After this has been completed, the fourth step consists of selecting the best solution that meets all or most of the requirements of the stakeholders involved. The fifth and sixth steps are to build a prototype of the solution and then test it to examine the solution’s feasibility and functionality. Afterwards, the seventh step is to improve the current design. This often involves presenting your solutions and experimental evidence to the stakeholders, taking their feedback and redesigning the solution to cater to these new needs and requirements (Hughes, 2015, 1). As can be seen in Figure 3, this is a cyclical process, which needs to be followed in its entirety, often multiple times, to ultimately achieve the best solution.

As a team of engineers, we followed this engineering design process. We followed these steps to find, at times repeating them multiple times, to come up with the best solution. .

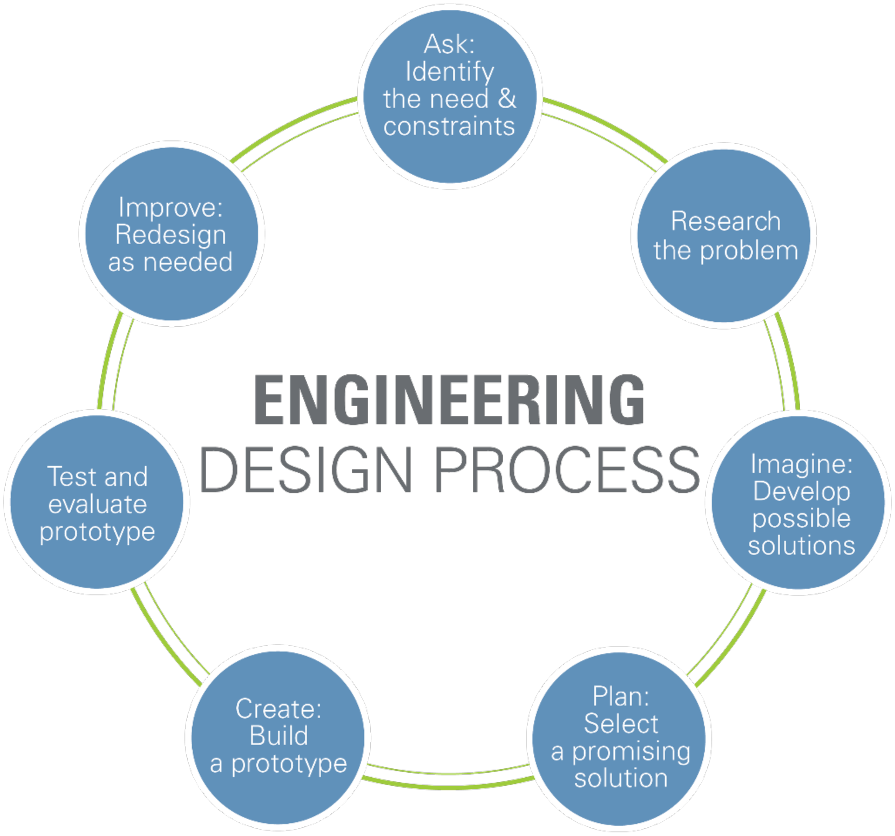


Figure 3: The Cycle of Engineering Design, (Teach Engineering, 2015)

2.2.2 Systems Thinking

In the words of Peter Senge, an American systems scientist, “systems engineering is a discipline for seeing wholes." It is a framework of seeing interrelationships rather than things, for seeing patterns of change rather than static ‘snapshots’.” (Frank et al., 2001, 362) In other words, systems thinking is the art and science of understanding how one particular component of the system affects the whole system. It’s a holistic approach used to understand how different aspects of a system are linked with each other, how they interact and what the system as a whole constitutes.

For example, think of a transportation system, which includes vehicles, traffic lights, roads, etc. Roads are the means of connecting two points, vehicles are a means of moving people from one point to another, and traffic lights make the movement safe and efficient. Now, any one of these components could cause problems in the system, affecting its overall efficiency: roads can get damaged, traffic lights could malfunction causing a hassle on the road causing congestion, and vehicles can breakdown unexpectedly. Thus, it is very important to understand the role of each element and subsystem to identify issues and solutions for the overall system (Ibarra, 2009, 6-9).

For our project we designed a subsystem of the overall drying process. Therefore, we had to consider how these changes would influence the rest of the drying process and, in turn, the entire manufacturing process. Systems thinking helped us develop a design that would not be detrimental to the efficiency and performance of the overall process.

2.2.3 Design of Experiments

Design of experiments is a an integral engineering concept and a branch of applied statistics which consists of "planning, conducting, analyzing and interpreting controlled tests to evaluate the factors that control the value of a parameter or group of parameters" (What Is Design . . ., 2015, 1). This concept is very advantageous when used strategically. Taking the time to properly design an experiment before conducting the test would certainly result in fewer problems during execution and analysis.

The idea is to design the experiment in a manner that provides a vast amount of information about the effect of different factors on the process. This involves keeping certain factors constant and analyzing the effect of others by varying them. Analytics have the liberty to alter one variable at a time or multiple variables at a time, depending on which cause-effect relationship they want to examine. Figure 4 shows a schematic of the concept.

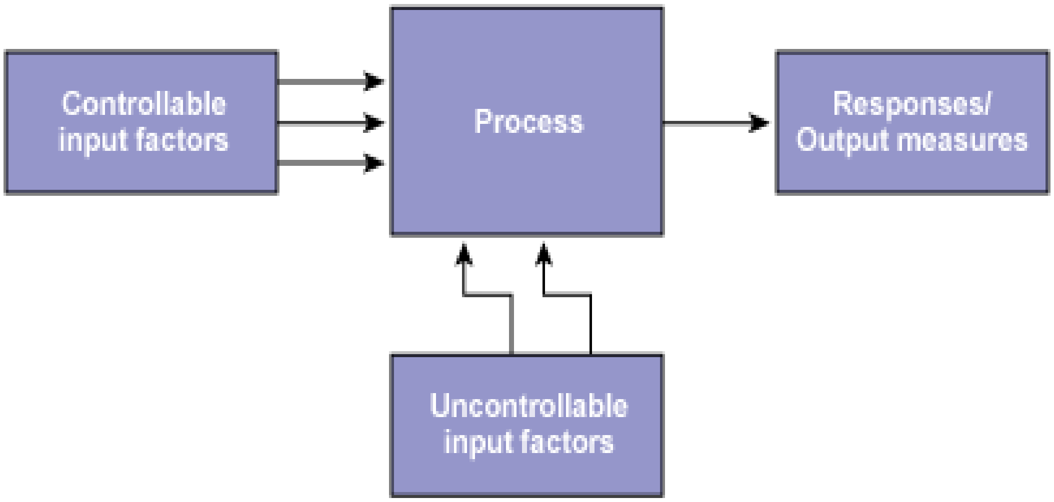


Figure 4: Process Factors and Responses (Sundarajan, 2015)

A well-conducted experiment would help analytics identify:

- Principal factors of the process;
- Optimum settings to obtain desirable results;
- Recognize the key interaction effects in the process;
- The settings of different variables, such that minimum variation is obtained in the results (What Is Design…, 2015, 1).

Furthermore, there are three key experimental approaches that analytics can take.

- **Randomization:** This refers to conducting trials randomly and without a bias. Doing so disregards the effects of unknown factors.
- **Blocking:** In cases where randomization isn't possible, blocking helps limit randomization i.e., all trials are carried out with one set of conditions and the following trials are carried out with different sets of conditions.

- **Replication:** This refers to the completion of the experiment multiple times from start to end i.e., set up to data collection (What Is Design…., 2015, 1).

In order to justify our proposed solution of integrating infrared radiation in the drying process at Pacific Can, we needed to conduct various experiments. Design of Experiment provided us with a great basis to strategically design tests and collect required data for analysis.

2.2.4 Cost-Benefit Analysis

Cost-benefit analysis (CBA) “is a technique used to compare the total costs of a [program or] project with its benefits, using a common metric (most commonly monetary units)” (Cost Benefit Analysis, 2015, 1). This helps businesses and other stakeholders see, in the form of tangible data, the costs and benefits associated with each choice. It is most commonly used at the beginning of a project when different options are being considered and compared. However, it’s also useful to conduct it at the completion of the project to identify performance and outcomes in monetary terms (Cost Benefit Analysis, 2015, 1).

In CBA, expected costs are summed and compared with the benefits, which are also calculated in monetary terms and are adjusted to the value of money at the time. CBA enforces analysts to consider all options explicitly and methodically as the costs and benefits are both “expressed on similar terms of value relating to the net present value or NPV” (Arnold et al., 2015, 26).

As we have recommended different alternatives to the current drying process at Pacific Can, it was essential for us to use this technique to compare pros and cons of all suggestions in order to help the company decide which solution is most suitable to its needs. Pacific Can will compare the CBA of proposed solutions with that of its current drying method to determine which process is most cost effective and energy efficient.

An important underlying concepts and calculations of the Cost Benefit Analysis that we used in this project is the return on investment (ROI). ROI is a measure of how much profit or savings are realized. To calculate ROI the benefit of an investment is divided by the cost of the investment and the result is expressed as a percentage or a ratio. The formula is as follows:

$$\text{ROI} = \frac{(\text{Gain from Investment} - \text{Cost of Investment})}{\text{Cost of Investment}}$$

Gain from Investment refers to the proceeds obtained from the sale of the investment of interest. ROIs are conveniently expressed as a percentage and can be easily compared to the ROIs of other cases.

2.2.5 Civil Engineering and Sustainability

As the world continues to become more and more environmentally conscious, the demand for sustainable designs and processes also grows. In the light of this, sustainable development has become a core education and training concept of civil engineering (Jowitt, 2004). This paradigm shift towards a more sustainable future is especially apparent at the university level where civil engineers begin their training. Universities are now emphasizing the importance of the incorporating sustainability concepts and principles in both professional practices and education in the field of civil engineering (Chau, 2007). In fact, At WPI the counterparts are housed in one department – Department of Civil and Environmental Engineering (WPI, 2015).

In China, and especially in the Beijing area there is a big concern with being environmentally friendly. The issue in China has been historically “linked to the industrial processes that are supporting China's economic development model.”(Brubaker, 2012) One of the tools by which Beijing is looking to tighten regulations and enforcement is technology;

specifically, technologies that would help reduce the industrial carbon footprint (Brubaker, 2012). Furthermore, at Pacific Can, sustainability is at the heart of the company's business model.

2.3. Drying Process of Different Industries

In general, the manufacturing of beverage aluminum cans is the same for many manufacturers. The cans start off as a 10 ton, 5 feet in diameter roll of aluminum sheeting as thin as construction paper. This roll is long enough to make 750,000 cans. From there it is fed to a press that punches out discs 5.5 inches in diameter that are then formed into cups. These cups then go into a lubricated body maker, which draws out the aluminum forming the body of the can. Then the cans are trimmed to the desired size. Afterwards, the cans enter the washing cycle.

At this stage some manufacturers differ in what they use to wash the cans. For the most part, they use a six stage washing process. During the first two stages, some manufacturers use hydrochloric acid, others use sulfuric acid, and others use patented solutions. The last four stages of washes are usually using deionized water. Next, the cans enter our area of interest – the drying process.

Different manufacturers use different techniques to dry the cans. Some use hot air dryers or blowers and others use an oven. The temperatures at which these blowers and dryers operate depend on the boiling point of the washing solutions. Generally, the temperature for air-drying the cans using blowers is between 163° C (325° F) to 190° C (375° F) (Rexam PLC, n.d.) and for oven drying is about 200° C (392°F) (Bell, n.d.) for about 30 seconds. Some patented washing solutions state that the solutions lowers the boiling point of the water in the cans closer to the 163° C (325° F) range and dry in about 20 seconds (PPG Industries Inc., 1998).

2.4 Infrared Technology

Since the major focus of this paper is on infrared and its application in the industrial drying system of Pacific Can, it is important to discuss its properties and the numerous ways we use it in our lives. In the following section we introduce infrared radiation and discuss the various applications of infrared technology. Getting a general sense of how such infrared technologies are used will help us determine a design for our solution.

2.4.1 Infrared Radiation

Infrared radiation is a type of electromagnetic radiation such as radio waves, ultraviolet radiation, etc. Infrared radiation is measured in microns (mm) and starts at .70 mm and extends to 1000 mm. We encounter infrared light, which is a part of the electromagnetic spectrum, on an everyday basis, but mostly it goes unnoticed.

Infrared radiation is one of the three methods of heat transfer, the other two being conduction and convection. Everything above 5 Kelvin or - 268 degrees Celsius emits infrared radiation. Half of the sun's energy is released in the form of infrared radiation; similarly, 90% of the electrical energy is incandescent bulbs gets converted in infrared radiation, while only 10% becomes visible light.

2.4.2 Applications of Infrared

Infrared has numerous applications in our day-to-day lives. For example, a remote control communicates with the television through infrared waves. Another very popular application of infrared is in sensing; since everything emits heat in the form of infrared radiation, it is this heat that the electronic sensors in night vision goggles detect. Moreover, it also has the following applications: in electric stoves to heat and cook food, in medicine to detect diseased tissues, in telescopes to observe planets that are in dusty regions, and in security alarms as it helps in motion detection.

2.4.3 Use of Infrared in Heating

While the range of infrared waves is between .70 and 1000 mm, it is most effective between 0.7 and 10 mm for infrared heating applications. More specifically for industrial applications, infrared radiation of wavelength 3 to 10 mm is ideal because almost all materials to be heated or dried exhibit maximum absorption in the 3 to 10 mm region (Basic Information About Infrared . . ., 1)

There are many kinds of infrared heaters available in the market for use in homes and industries. These include metal sheath element, quartz tubes, quartz lamps and ceramic elements. Metal sheaths element are best for convention needs, like in an oven. Quartz tubes are most desired for radiation purposes and can be turned on and off instantly. Quartz lamps are made in high wattage density and are most useful for high-speed processes. Ceramic element heaters are most useful in systems requiring an even temperature throughout; they can be controlled with a thermostat (Basic Information About Infrared . . ., 1).

For this project, we focused on Quartz tube heaters. They are reasonably priced, heat up quickly, have a good lifespan, and have a maximum operating temperature of 876 degrees Celsius (or 1600 Fahrenheit). They come in many different sizes and can fit perfectly into the space available at the manufacturing line at Pacific Can. Lastly, their efficiency of converting electricity to infrared radiation is 61%. Figure 5 depicts a regular Quartz tube heater (Basic Information About Infrared . . ., 1).

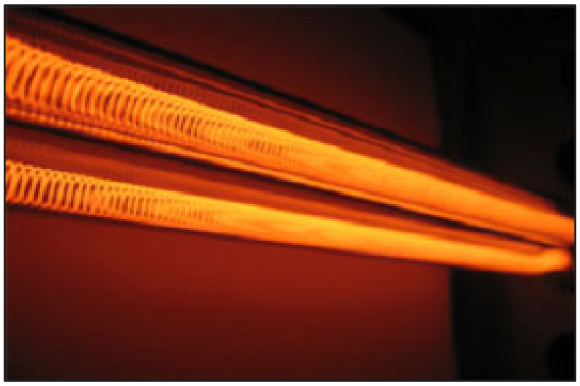


Figure 5: Quartz Tube Heater (Basic Information About Infrared (Radiant) Heating)

2.5 Use of Infrared in Various Drying Processes

Our team will be attempting to integrate infrared technology into the current drying process of Pacific Can. Use of infrared radiation for drying is a widely known concept from the food industry to the paper industry to the metals industry. In the food industry, infrared radiation is being experimented with and multiple patents have been created for drying systems that use infrared radiation in a variety of fields. The radiation affects the exposed material by penetrating it with its waves whose energy is then converted into heat. This heat is used to dry the material by evaporating the moisture. The energy consumption for infrared radiation is lower than that of a hot air dryer or an oven. By not giving off heat to the surrounding air but transferring the energy to the materials' surface, the element is much more efficient. (Sharma, Verma, & Pathare, 2005)

Infrared radiation has been used to dry onion slices. A drying chamber was made to do this. This drying chamber was created from 8 mm thick boards of plywood. Out of these boards of plywood a box was created with 400x300x300 mm as dimensions. The inside of the box is covered in aluminum foil and there is an air blower to create airflow within the box. The onions were sliced into 6mm thick pieces that had 7.4 grams of water per gram of dry matter. There were successful trials with 300, 400 and 500 watts of power going through the infrared tubes with air temperatures of 35, 40 and 45°C and air velocities of 1, 1.25 and 1.5 m/s. These trials dried the onion slices to 0.06 g water/ g dry matter. (Sharma et al., 2005) This case relates to our project because we will be working with a similar infrared drying system that dries cans instead of onion slices.

Another case of an infrared radiation oven working as a successful drying system is a case regarding the drying of fresh and sugar-infused blueberries. Initially, the moisture content of these blueberries by mass was 85%, and they had an average diameter of 12mm. The blueberries were exposed to an average infrared radiation intensity of 4000 W/m^2 the berries were tested in four drying temperatures: 60, 70, 80, 90°C using 10-15 grams of blueberries. The goal was to have a water activity of 0.6 in the blueberries. The fresh blueberries experienced 80% weight loss and the sugar infused berries experienced 30%. The amount of moisture that was removed from the berries was greatly increased and the amount of time needed to reach this goal was greatly reduced. At 90°C the drying process took 90 minutes and was 91% more effective. (Shi et al., 2008)

There are a few patented designs of drying systems that use infrared radiation to dry the products. One of these patented designs is a system that uses a combination of forced air and the infrared dryer. This design uses drying nozzles that blow warm air onto the product to assist in drying while the product moves through an area that has infrared tubes positioned to dry as well. (Townsend, 1981) Another patented drying system uses a small alternating bursts of the infrared radiation and cold air. Keeping heat sensitive products at a temperature that will allow for the thin aqueous layers on heat sensitive materials to dry without any distortion or damage. This drying system uses between 60 and 160 watts per in^2 of the infrared radiation to dry the materials. (Hyde, 1985) A final drying system that is already patented is a drying system for wide webs of materials, such as paper. This drying system uses infrared radiation to dry the material and also contains sensors that are able to detect temperature, moisture and other physical properties. This feature allows for this drying system to control the temperature and moisture of the materials. (Treleven, 1991) These systems contain ideas that could potentially be used to improve the design of our solution.

2.6 Design and Recommendations from Previous MQP

Currently at Pacific Can, the method for transporting the cans is a conveyor belt, which runs for 7.8 seconds from the washer to the drying oven and allows water to drop. Cans then enter an industrial size oven running at temperatures of over 200 degrees Celsius, containing the cans for 50 seconds. If those cans are directly transmitted into the drying oven, the energy consumption during the drying process increases a great deal because of the amount of residual water that needs to be dried (Arnold et al, 2015, 4).

The team of students, who previously worked on improving the drying process at Pacific Can, recommended the installation of infrared tubes underneath the conveyor belt carrying cans from the washer to the oven. This region would have an aluminum box around it to retain heat, along with a ventilation system to remove residual moisture. The hot air removed during ventilation would then be cycled back into the box. Cutting down on the cleaning that would be necessary to avoid rust and allow the inside of the box to retain its luster and reflective properties (Arnold et al, 2015, 5). The figure below shows an illustration of what the system would look like.

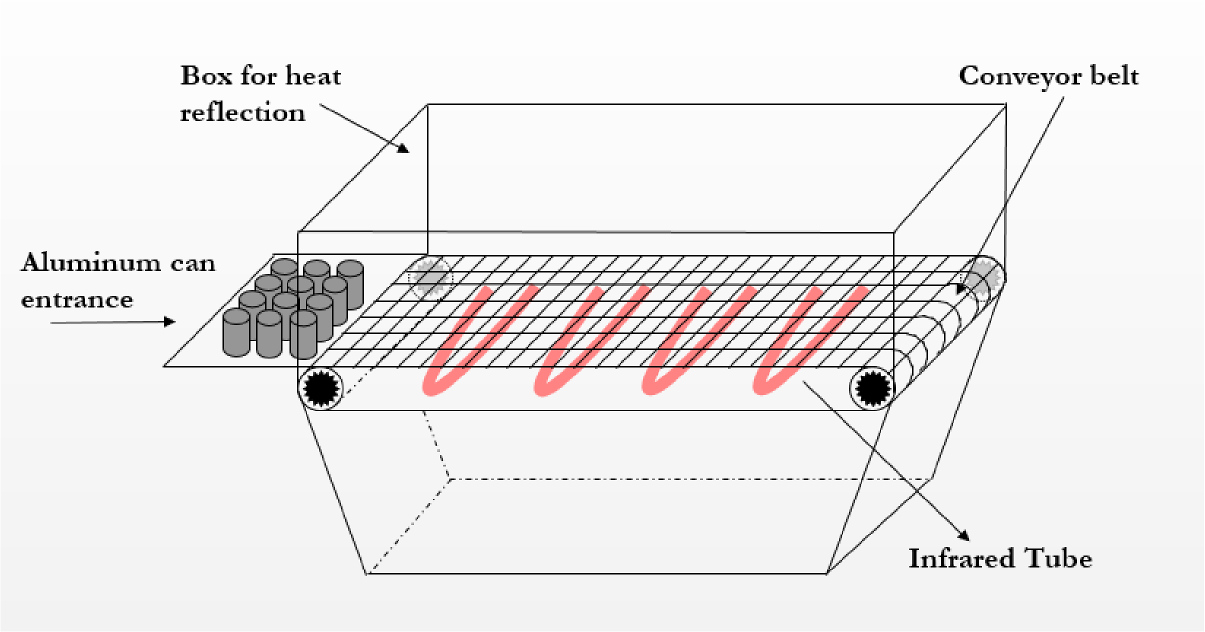


Figure 6: Illustration of the proposed infrared system in the drying process (Arnold et al.., 2015)

With the capability of the infrared tube, they found positive signs in their results from the lab experiments that prove potential feasibility within the industry. They found a return of investment (ROI) for infrared tube system to be approximately 264% when completely replacing oven using infrared tubes (Arnold et al, 2015, 6).

3. Methodology

The goal of this project is to assist Pacific Can in determining and implementing a more efficient and economical drying system into the manufacturing process of aluminum cans. The team of student from WPI that completed their MQP in the summer of 2015 provided a list of recommendations to help improve the company's drying process. Our main focus was to follow their work, analyze their results and recommendations, design an efficient model, and determine the best solution to achieve our overall goal of this project. In order to do so, we completed the following objectives:

(1) Analyze the current process at Pacific Can

(2) Analyze previous team's results and recommendations

(3) Perform experiments with larger quantity of sample cans

(4) Design a SolidWorks model of the improved process

3.1 Analysis of the Current Process at Pacific Can

Our first objective was to analyze the current drying process at the Pacific Can manufacturing facility. To do so we visited the site, where we spoke with our sponsors and observed the current drying process. This visit allowed us to ask the engineers there any questions we had regarding the existing process and discuss possible alternatives and their feasibility. Moreover, we became aware of the concerns of the company, in regards to the recommendations made by the previous team, which in turn allowed us to tackle these issues through our research and ultimately make adjustments to our model.

3.2 Analysis of Previous Results and Recommendations

As our project was a continuation of the summer team's work it was imperative that we looked deeply into their project report. It was very advantageous for us to be working with the same group of students from BUCT as the previous team. The BUCT students helped us understand the previous work in much more detail. Professor Dazi Li from BUCT also helped clear any doubts we had as she too had worked with the preceding team.

3.3 Performing Experiments with Larger Quantity of Sample Cans

In order to test the feasibility and functionality of using IR tubes in the drying process, the previous MQP team conducted a simulation of the suggested process in a lab at BUCT. Due to a lack of time and resources, they could only perform experiments with one can at a time. However, three hundred cans enter the drying process simultaneously in the manufacturing facility. In order to conduct an experiment similar to the real scenario, we tested the performance of the IR tubes with 25 cans at a time.

3.3.1 Lab Experiment

In order to carry out the experiment we needed the following items:

- Twenty five 330 mL cans
- Heat containment box
- A tray to carry 25 330 mL cans
- Two sets of infrared tubes.

Our team created a heat containment box using Aluminum sheets provided by Pacific Can. This heat containment box was able to hold two infrared tubes and 25 of the 330 mL cans. The cans were held on a tray that was made of chicken fencing (Figure 7); the tray held the cans in a five-by-five square. The sides were extended to prevent cans from falling out.

Figure 7: Container made from Chicken Wire holding 25 Cans

Two sets of infrared tubes (two tubes per set) were purchased and fixed into the heat containers. These containers were made of Aluminum and reflected the light and energy from the IR Tubes upwards towards the cans. The two sets were placed in the heat containment box, ten centimeters apart as shown in Figure 8 below.

Figure 8: Heat containment box within IR tubes 10 cm apart

Using this simulation, we ran two different experiments. The first experiment measured the amount of water that would evaporate and drip off the cans after 10 seconds. This experiment was run to determine the effectiveness of having the new IR drying system integrated before the oven. The second experiment was used to record the amount of water that would evaporate and drip from the cans after 50 seconds – the approximate time the cans are currently in the oven the Pacific Can facility. This experiment was carried out to determine the effectiveness of replacing the oven with infrared tubes. The overall set up of the experiments is depicted in the figure below.

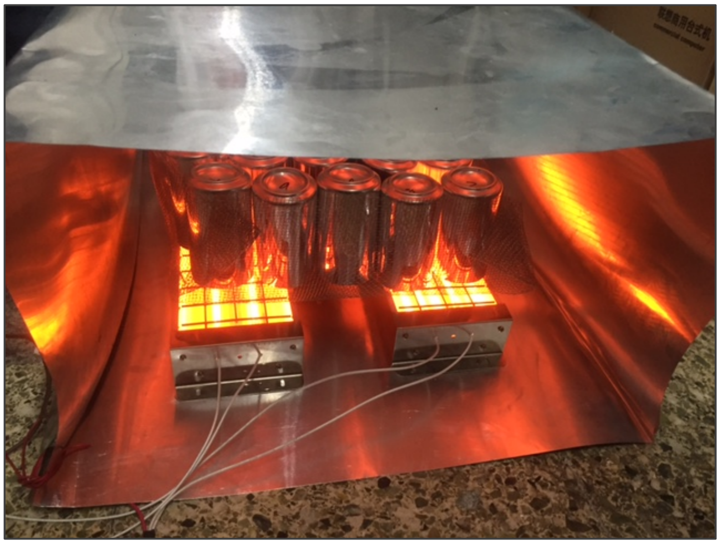


Figure 9: Experimental Setup

The following flow charts represent a step-by-step breakdown of the experiments.

First Experiment (10 seconds):

1. Place 25 330 mL cans in the chicken wire tray
2. Number the cans, 1 through 25
3. Take out cans 1 through 5
4. Weigh each can individually and record its mass
5. Spread 1 mL water using a syringe onto each can
6. Weigh the can again and record new mass
7. Put the can back in the tray
9. Place the tray carrying all 25 cans in the oven
10. Take it out 10 s later
11. Reweigh each can and record new mass
12. Repeat Steps 3 -11 for the remaining 20 cans (5 cans at a time)

<u>Second Experiment (50 seconds)</u>:

1. Place 25 330 mL cans in the chicken wire tray
2. Number the cans, 1 through 25
3. Take out cans 1 through 5
4. Weigh each can individually and record its weight
5. Spread 1 mL water using a syringe onto each can
6. Weigh the can again and record new weight
7. Put the can back in the tray
9. Place the tray carrying all 25 cans in the oven
10. Take it out 50 s later
11. Reweigh each can and record new weight
12. Repeat Steps 3 -1 1 for next 20 cans, 5 cans at a time

It is important to note that both of these tests were carried out twice in their entirety to obtain a larger amount of data for a reliable analysis.

3.4 Design the SolidWorks Model of the Improved Process

During our first visit to the company, Pacific Can offered to construct a simulation based on our design in their factory for us to run tests on. Thus, we designed a 3D model using SolidWorks with detailed drawings. After making improvements to the design based on feedback we got from our advisors, we sent the files to Pacific Can for manufacturing of the model. However, due to time constraints this simulation was not constructed. Although this simulation was not completed, Pacific Can was given the drawings for the system found in Appendix A along with Instructions for Constructing Experiment Setup.

3.5 Sustainability in our Design

Pacific Can's commitment to the environment stems from their entrepreneurial mindset when it comes to running their business. In the organizations aim to protect and respect the environment, they state that they are "committed to environmentally sound business practices" and "the sustainable development of the aluminum beverage can market in China." (Pacific Can Co. Ltd., 2011) An innovative idea today is short-lived if not also considerate of its effects on the surrounding environment. Thus, it is necessary to analyze the potential measures that could be applied to make our design as sustainable as possible.

We conducted our analysis using the following assessments (Stevens, n.d.):

1. Identify level and target landscape
2. Identify sustainability capabilities and relevant tools
3. Report findings

3.6 Overview of Research Methods

The following table summarizes the methods used to accomplish our overall goals and objectives:

Method	**How it was used**	**Outcome**
Engineering Design	Followed the whole process multiple times to ultimately create the best 3D model to be constructed by Pacific Can.	After a couple of iterations, finalized a design approved by the project advisor.
Design of Experiments	Designed experiments where effect of one variable i.e., time, was tested. Used both blocking and randomization techniques when picking can samples for analysis.	Discovered that drying the cans with IR for 10 s dried them by an average of 64% while doing the same for 50 s completely dried the cans.
Cost-Benefit Analysis	Compared costs of alternatives to current process in order to find cost effective alternative	Discovered most cost efficient alternative and ROI.
Systems Thinking	Looked at externalities in other processes that might be affected by alternatives or externalities that might affect the alternatives.	Changes to drying process based on our recommendations would not have known effect on other aspects of the system.
Civil Engineering and Sustainability	Analyzes the potential measures that could be applied to make our design as sustainable as possible	Infrared tubes are very recyclable, and generation of power in China was found to become more sustainable in the future.

Table 1 Summary of Methods

3.7 Timeline of the Project

While working on any project, it is extremely important to stay organized, prioritize and manage time well. Thus, we created a timeline to help us stay on track and complete all the tasks we needed to accomplish. We tried our best to adhere to a timeline we made at the beginning of the term, but we had to adapt and alter it a few times due to some obstacles and unforeseen circumstances that we touched upon in Chapter 6.

Task	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Assess the current drying process	■						
Conduct preliminary research and experiments	■	■					
Create model and drawings of proposed solutions		■	■	■			
Improve the drawings based on feedback from advisors				■	■		
Build a larger prototype in lab and experiment with 25 cans					■	■	
Analyze data collected from experiments					■	■	
Send drawings to Pacific Can						■	
Conduct a Cost-Benefit analysis						■	
Gather findings and recommendations and complete report						■	■

Prepare and give a final presentation to sponsor						▨	▨

Figure 10: Project Timeline

4. Analysis and Results

In this chapter, we describe our analysis and results in detail. In order to provide valuable recommendations to Pacific Can, we analyzed the data from all our experiments along with stating any errors that may have affected our data. Furthermore, we explained the design of our proposed model with infrared tubes. Lastly, we provided a summary of cost-benefit analysis, which ultimately helped us decide the best option Pacific Can should move forward with.

4.1. Experimental Data

From the experiments performed in the lab on the Beijing University of Chemical Technology campus we were able to find data on how the drying of cans was affected by the amount of cans in the drying system and the proximity of the cans to the infrared tubes from our experiments of having the cans in the drying system for 10 seconds and then again for 50 seconds.

In the ten second experiments it was found that the average amount of water remaining on the cans after going into the system was on average 0.2232 g from the first tests and 0.2508 g from the second tests giving an overall average of 0.237 g of water remaining on the cans. This means that the percentage that the cans dried on average for the first tests was 65.83% and in the second test 62.14%. Overall, the cans dried on average 63.985%. Figure 10 shows the average dryness of cans with respect to their location, along with the standard deviation of the data. The standard error for each position is less than 10%. Table 2 summaries this information.

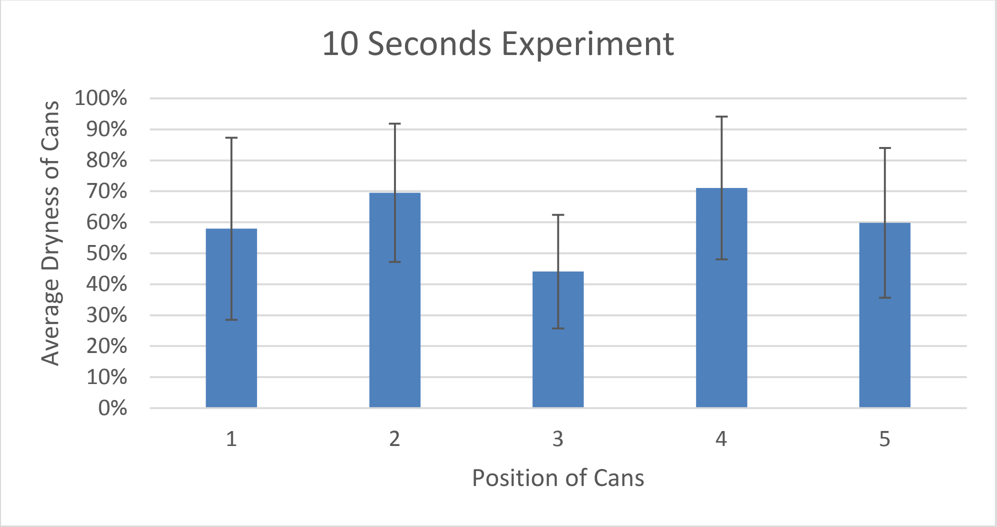


Figure 11: Average Percentage Dryness vs. Position of Cans (10 Seconds Experiment)

Position	Average Dryness	Standard Deviation	Standard Error
1	57.94%	29%	9%
2	69.52%	22%	7%
3	44.10%	18%	6%
4	71.11%	23%	7%
5	59.84%	24%	8%

Table 2: Data Summary for 10 s Experiment

In the 50-second experiments it was found that the cans would be an average of 100.76% dry in the first test and 101.65% dry in the second test. Overall the cans would be 101.21% dry on average in the experiment. While it is not possible for cans to be more than a 100% dry, the standard deviation and standard errors for each position presented below explain this anomaly. In spite of this, the standard error for each position was about 5%, which is a very positive sign.

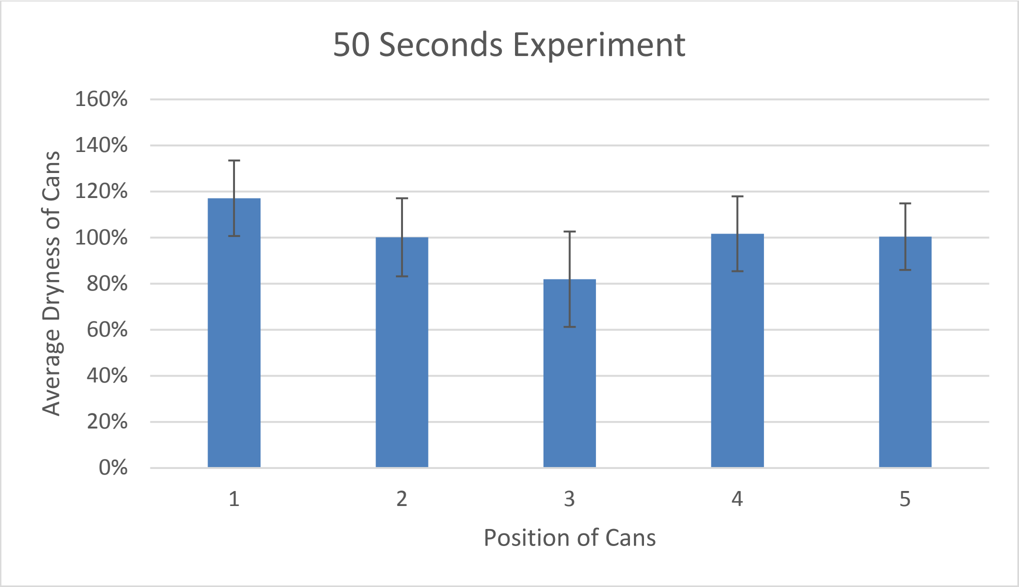


Figure 12: Average Percentage Cans Dried vs. Position of Cans (50 Seconds Experiment)

Position	Average Dryness	Standard Deviation	Standard Error
1	117%	16%	5%
2	100%	17%	5%
3	82%	21%	7%
4	102%	16%	5%
5	100%	14%	5%

Table 3: Data Summary for 50 Seconds Experiment

From the data collected in both experiments we were able to determine which locations were the most effective at drying the cans. It was found that the cans in between the two sets of infrared tubes would dry less than cans directly over the infrared tubes. The bar graph below shows the overall relationship of the can location in the heater and the percentage of dryness.

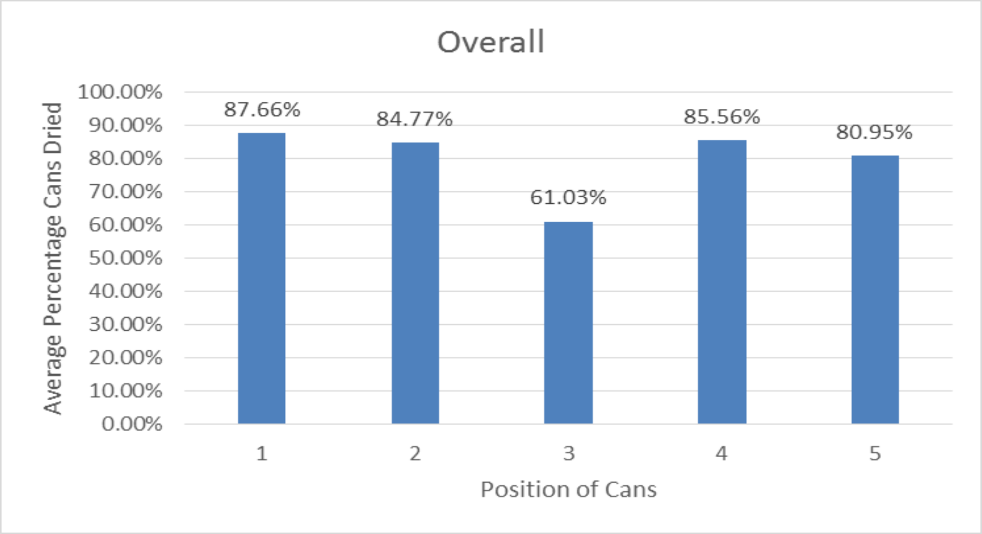


Figure 13: Average Percentage Cans Dried vs. Position of Cans (Overall)

The can locations span across the oven from one set of infrared tubes to the other. Cans that were placed in position 1 are cans 1, 6, 11, 16, and 21. Cans that are classified as being in position 2 are cans 2, 7, 12, 17, and 22. Cans that are classified as being in position 3 are cans 3, 8, 13, 18, and 23. Cans that are classified as being in position 4 are cans 4, 9, 14, 19, and 24. Cans that are classified as being in position 5 are cans 5, 10, 15, 20, and 25. As you can see in Figure 13 the cans in position 1 and 5 are directly above the infrared tubes, cans in positions 2 and 4 are partially above the infrared tubes and cans in position 3 are not above the infrared tubes at all.

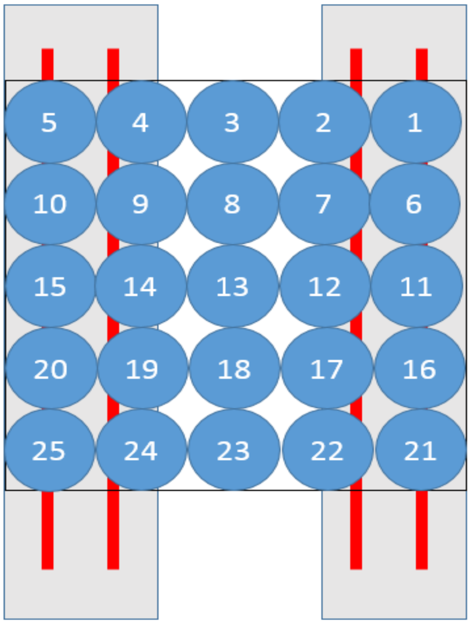


Figure 14: Layout of Cans in Oven

Figure 14 depicts the detailed layout of cans in the system. It is important to note that cans in position 3 were not exposed to the infrared tubes as much as the cans in positions 1, 2, 4, and 5. Are team believes that this will not be an issue when the cans are in the simulation at the Pacific Can facility because we believe with the added distance between the cans and the infrared tubes all of the cans will be exposed to the infrared tubes. Although, we expect this distance to have a negative effect on the drying capacity over a period of time due to the increased space between the infrared tubes and the cans.

In these experiments there were multiple sources for error. One source for error in our experiment would be water dripping off of the cans before the cans were weighed and while the tray of cans was being transported from the heat containment box to the molecular scale. This would affect the data because of the amount of water that was lost over the time in the box would be less than the measured amount. This was also affected by the fact that only one can could be weighed at a time, this allowed more water to drip off the cans while the other cans were being weighed. Another possible source for error in our experiment was the inability to wet the cans with 1 mL of water evenly. Due to having to use syringes to measure and apply the water to the cans the water wasn't spread on the can as well as it would be from the washing process.

These errors can be reduced through the use of a conveyer belt in the experiment to the amount of water lost during the experiment from moving the cans. Using a washing process similar to the one in the manufacturing line will result in the more accurate spreading of water onto the cans. Overall, creating a simulation for experiments that is identical to the washing and drying processes will yield the most accurate results.

In spite of the aforementioned errors the standard error for both experiments is close to 3%. The standard deviation error bars in Figure 15 along with a data summary in Table 4 illustrate the magnitudes of these errors.

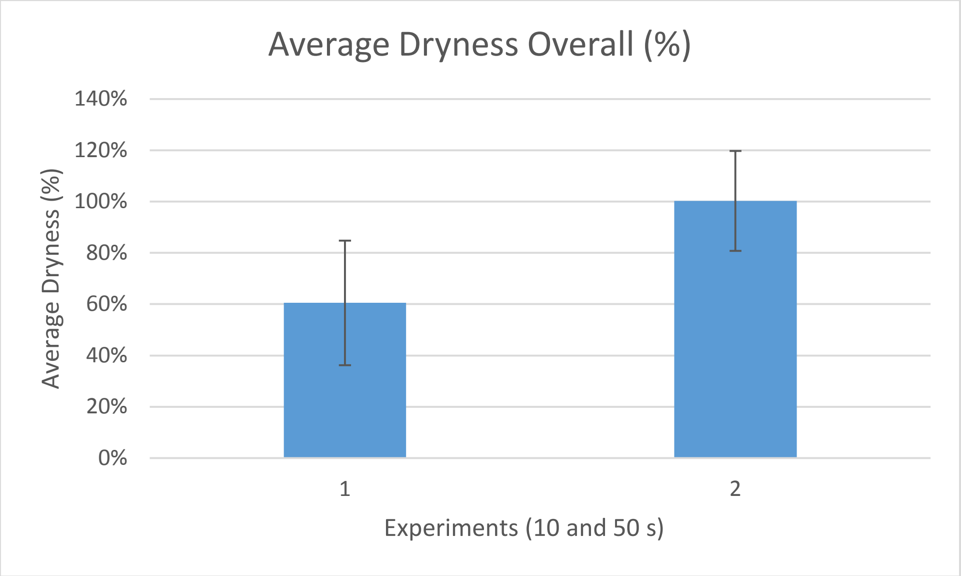


Figure 15: Overall Percentage of Drying in Cans with Error Bar

Experiment	Average Dryness Overall	Standard Deviation	Standard Error
10s	60.50%	24%	3%
50s	100.26%	19%	3%

Table 4: Overall Summary of Data for Both Experiments

4.2 Three-Dimensional Model and Drawings

The team created a three-dimensional model of the system that is believed to be the most effective for Pacific Can. This system is what our team plans to use for the simulation experiments at Pacific Can. The system is created from 10 manufactured parts, which two-dimensional drawings have been made for. The designed system also has four sets of infrared tubes as well as eight #5 binding head machine screw and two #00 binding head machine screws. The #5 binding head machine screws are used to construct the heat containment box for the system and the #00 binding head machine screws are used to construct the two locking mechanisms (one for each drawer). It was decided to have two drawers with one on each side of the conveyor belt to allow for easier replacement or repair should one malfunction or break.

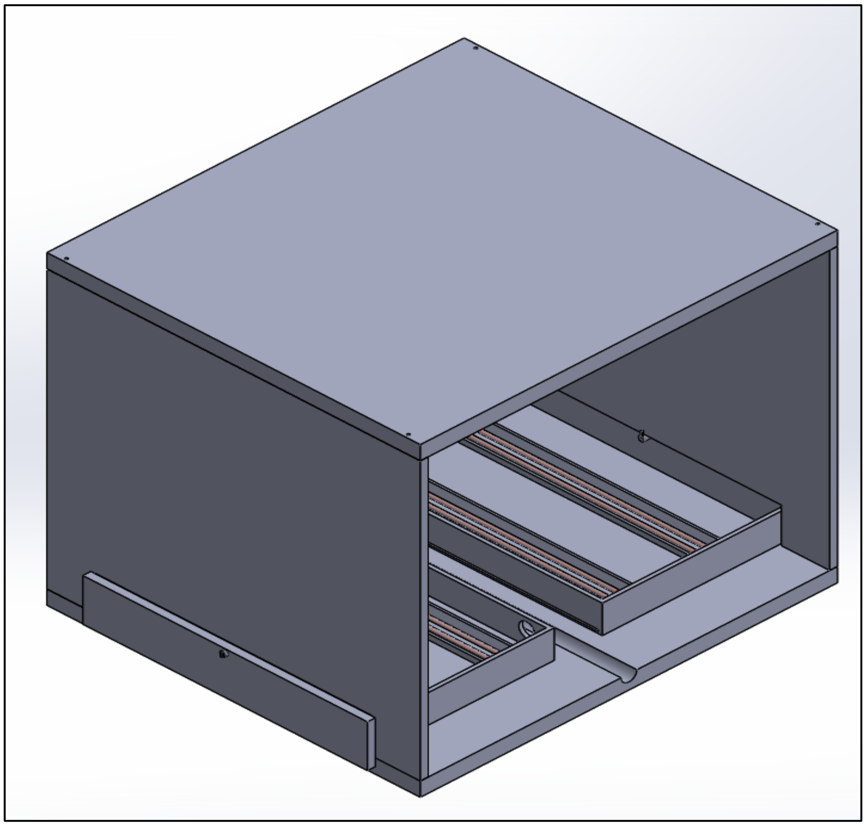


Figure 16: 3D Model of Drying System

The drawing of the bottom of the heat containment box is seen below. This part is 120 cm long, 134.08 cm wide and 5.08 cm high. In this drawing you can see how the bottom of the box was designed with a round cut in the center with a 2.54 cm radius to allow the water that has dripped off the cans to run out of the system. There is also a 7.62 cm hole in the bottom of the box to allow wires for the infrared tubes to be thread from the tubes (inside the box) to the control panel (outside the box). This holes center is located 7.62 cm from the round cut in the center and 10.16 cm from the left edge. There are also 4 holes in the corners of the bottom of the box with 0.35 cm diameters for the insertion of the #5 binding head machine screws. Detail J shows the location of these holes.

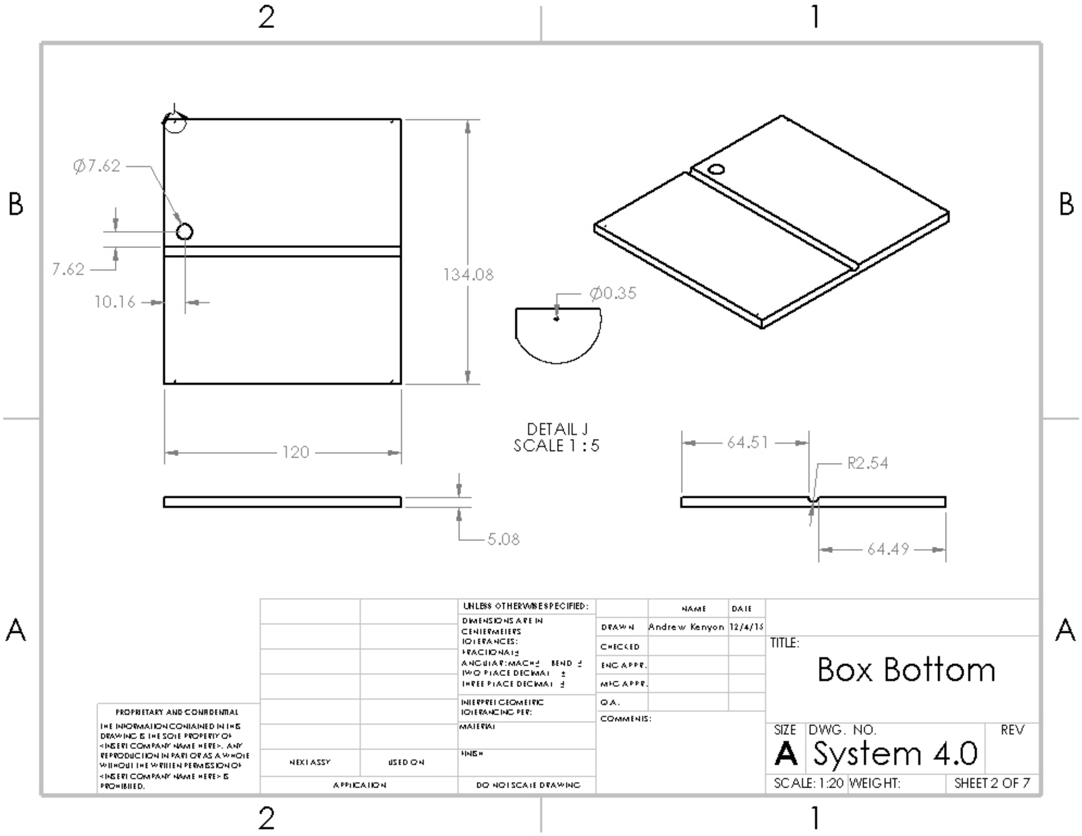


Figure 17: Bottom of Heat Containment Box

The drawing for the sides of the heat containment box is seen below. For the system, two of this part will need to be manufactured. The side of the box is 120 cm long, 2.54 cm wide and 100 cm high. The sides of the heat containment box have rectangular cut outs in the bottom that are 88.90 cm wide and 12.70 cm high. These cut outs are located 15.54 cm from the left edge of the part. At the top and bottom of the part there are holes at both ends. These holes are for the #5 binding head machine screw for the assembly of the box.

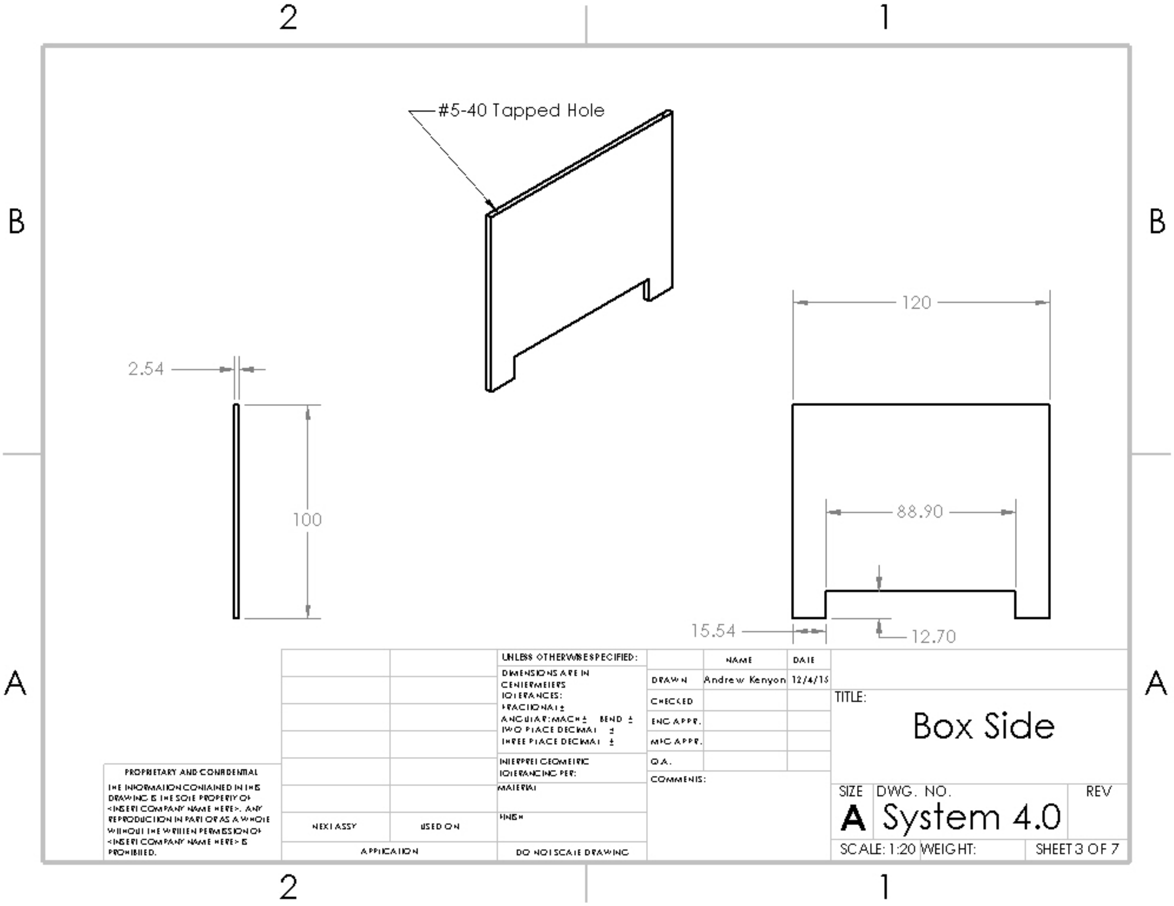


Figure 18: Side of Heat Containment Box

The top of the heat containment box can be seen below. This part is 120 cm long, 134.08 cm wide, and 5.08 cm high. This part has four holes in it in each corner that are 0.35 cm in diameter with a 0.75 cm in diameter countersink. Detail G shows the location of these holes.

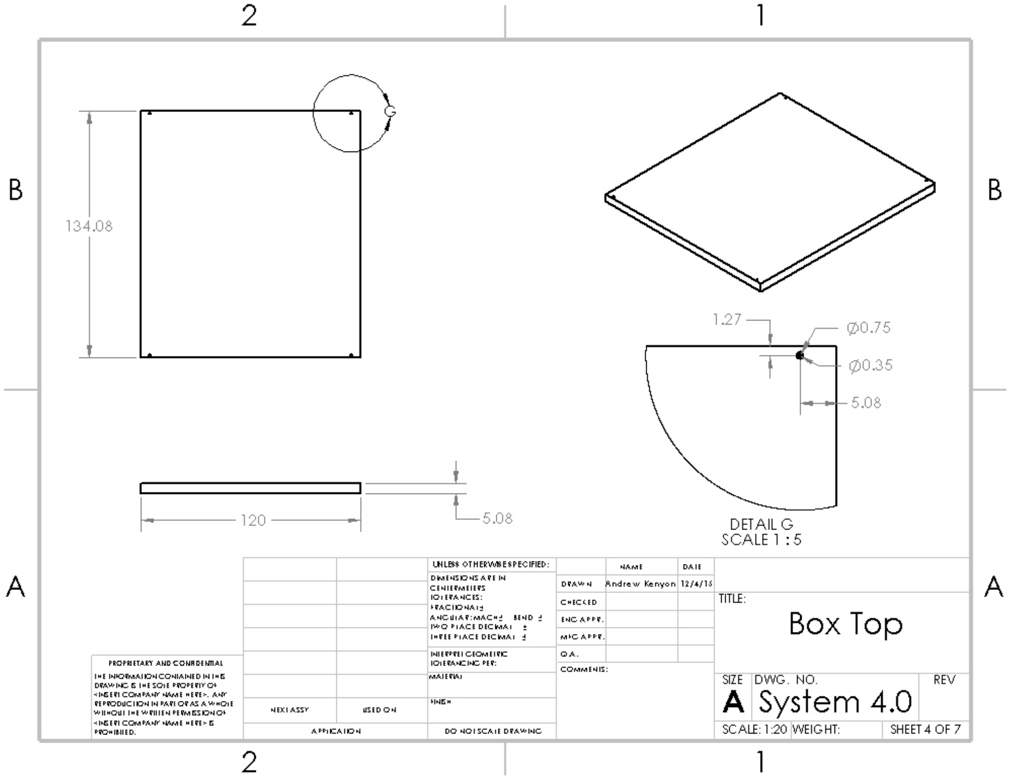


Figure 19: Top of Heat Containment Box

The drawings for the drawer of the system can be found below. For the system, there will need to be two of this part manufactured. The drawer is a much more complex part than the parts of the heat containment box. The front of the drawer is 91.44 cm long, 2.54 cm wide and 15.24 cm high, this section of the part has a hole in the middle of it with a 1.27 cm diameter. This hole is close to the top edge of the front of the drawer and for the locking mechanism, which will hold the drawer shut. The base of the drawer has a slight incline, which allows the water drops to flow out of the drawer into the round cut in the bottom of the heat containment box. The drawer has a slit in the back for the water drops to flow through to exit the drawer. The back of the drawer also has a hole with a 5.08 cm diameter that allows the wires of the infrared system to be thread through to keep the wires organized while the system is in use. The walls of the drawer are 1.27

cm thick and create a 59.41 cm by 87.63 cm rectangle on the base; the infrared tubes will be put inside of this rectangle. The walls of this drawer are 10.16 cm high from the bottom of the base to the top of the drawer wall.

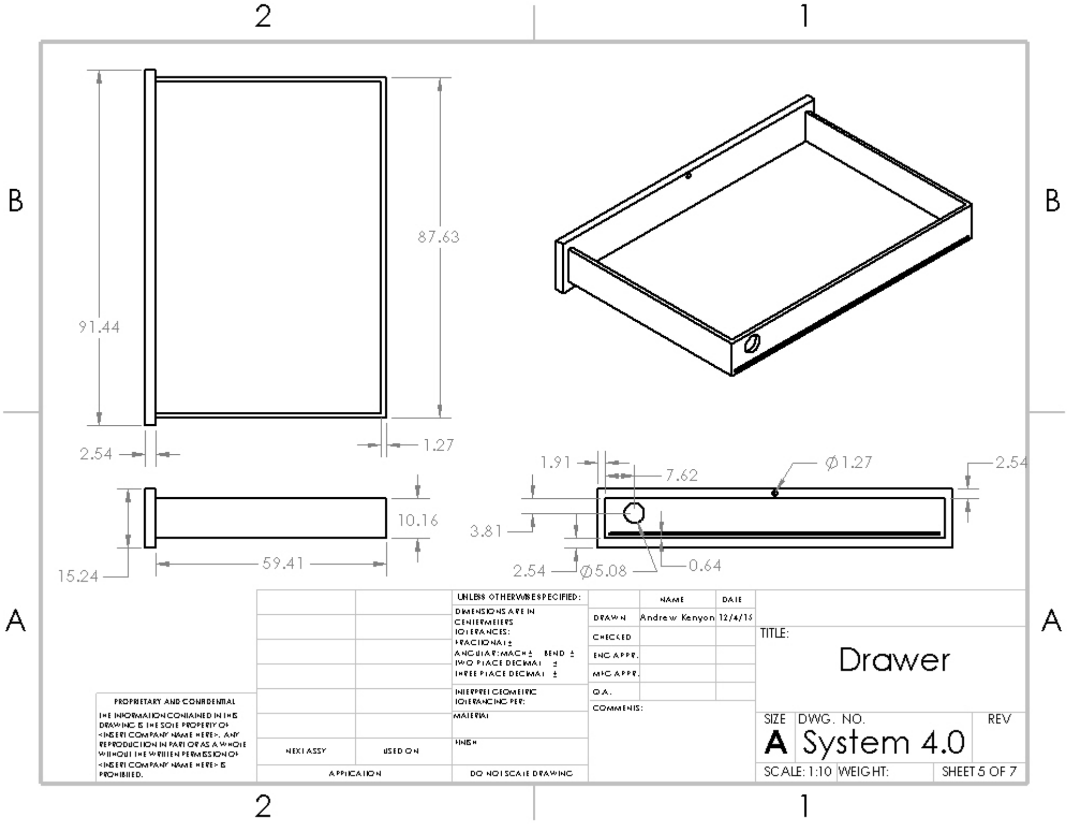


Figure 20: Drawer

The first part of the locking mechanism is seen in the drawing below. For the system, two of this part will be manufactured. This part has a cylindrical shaft that has a diameter of 1.27 cm and a length of 5.08 cm. This shaft has a rectangular cutout in the middle of one end that is 0.51 cm wide and 0.51 cm deep. In the center of this cutout there is a tapped hole for a #00 binding head machine screw. On the other end there is another cylinder with a 1.91 cm diameter and a

0.76 cm length. At the end of this cylinder there is a 0.51 cm by 1.52 cm rectangular boss that is 0.51 cm high. This boss will be used to operate the locking mechanism.

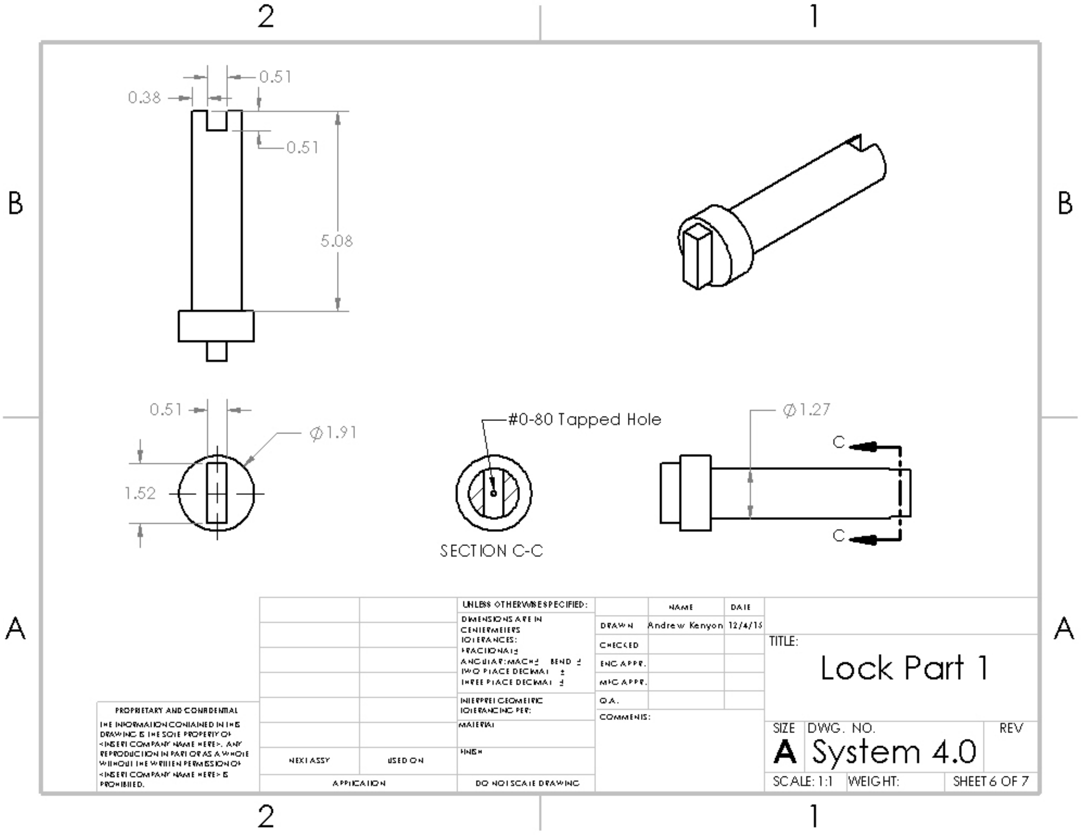


Figure 21: Locking Mechanism Part 1

The drawings for the second part of the locking mechanism can be found below. For the system, two of this part will be manufactured. The base of this part is a 3.05 cm long cylinder with a diameter of 1.91 cm. This cylinder has a rectangular boss protruding from one end, it extends 2.54 cm from the center of the cylinder and has a width and length of 0.51 cm. at this same end in the center of the cylinder there is a hole for a #00 binding head screw with a 0.32 cm diameter countersink. At the other end of the cylinder there is a 1.27 cm diameter, 2.54 cm deep hole that is in the center of the cylinder. At the end of this hole is a rectangular boss that is 0.51

cm high from the end of the hole and 0.51 cm wide. This part of the mechanism slides over the other part of the locking mechanism to construct the locking mechanism.

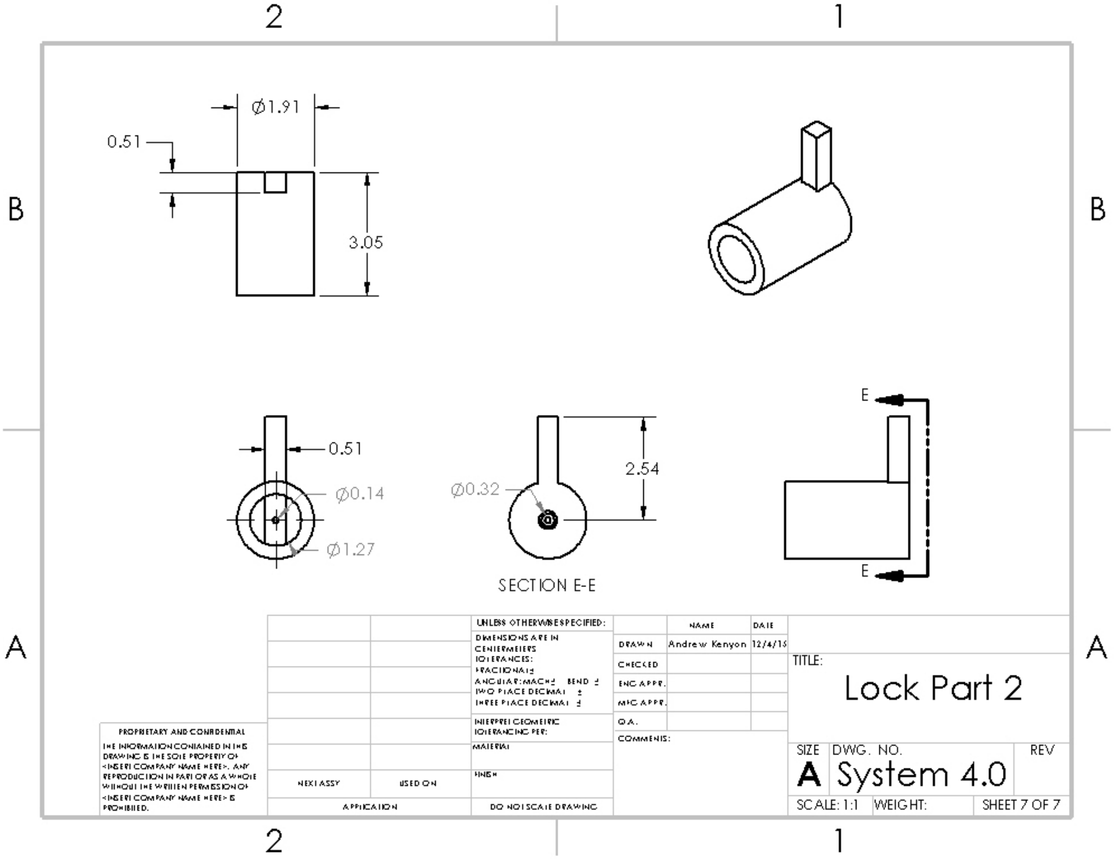


Figure 22: Locking Mechanism Part 2

The drawing below is of the full assembly. This drawing gives details of what the assembly should look like after being constructed. The full assembly has one heat containment box (one top, one bottom, and two sides), two drawers with locking mechanisms (drawer, lock part 1, and lock part 2 each), four sets of infrared tubes (two infrared tubes and one containment each), eight #5 binding head machine screws and two #00 binding head machine screws.

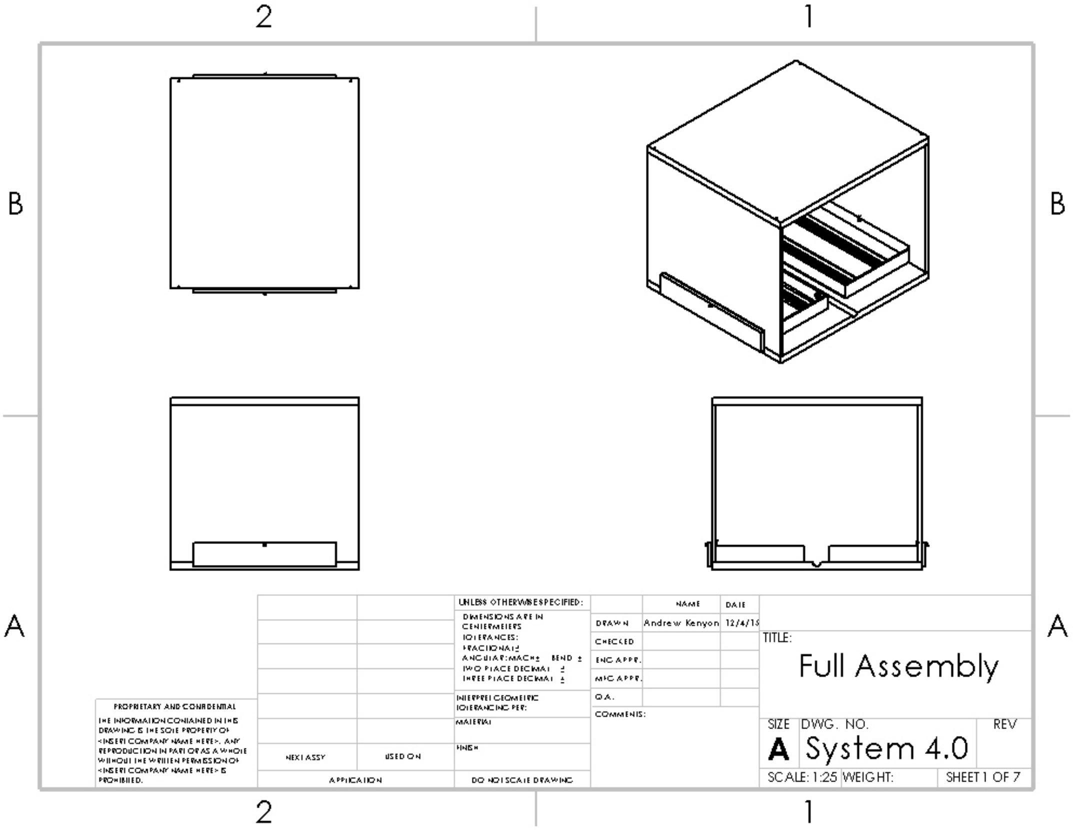


Figure 23: Drawing of the Full Assembly

To create the full assembly the heat containment box must first be constructed using the box bottom, box top and two box sides around a conveyor belt. Using four #5 binding head machine screws attach the two box sides to the box bottom so that all of the edges are flush with adjacent edges. Using four more #5 binding head machine screws attach the box top to the 2 box sides so that all edges are flush like the edges at the bottom. Next, take one of the two drawers and slide one of the lock parts 1 that was manufactured through the 1.27 cm hole in the drawer with the end with the larger diameter cylinder sticking out of the drawer. Then take a lock part 2 and attach it to the lock part 1 end inside the drawer. The boss inside the lock part 2 should fit into the cut out in the lock part 1, once the two parts are together correctly use a #00 binding head screw to hold the two parts together. Assemble the other locking mechanism in the same fashion to the second drawer. Insert the drawers into the cutouts in the assembled heat containment box. Insert the infrared tubes into the contaminants that were provided with them and then insert them into the drawers. The infrared tubes should be parallel with the box sides and as evenly spaced as possible along the width of the conveyor belt to allow the cans to dry as evenly as possible. The top of the conveyor belt should run through the box and the bottom should run underneath it.

4.3 Cost-Benefit Analysis and Summary

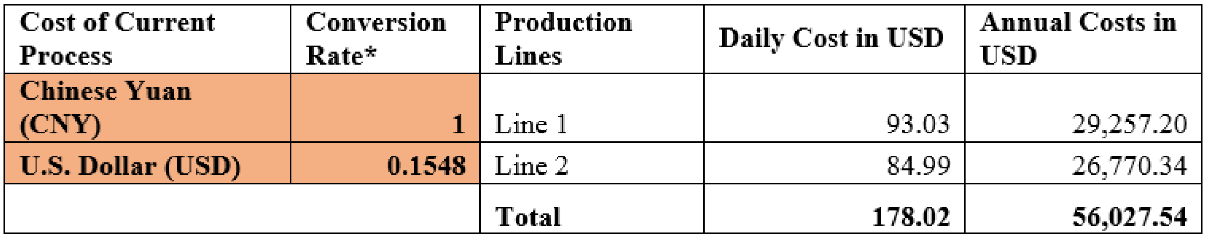
Although we know our infrared solution's efficiency benefits, we do not know of its monetary benefits. Thus, we conducted a cost benefit analysis. First, we conducted the analysis for completely replacing the current drying process using infrared technology. Then, we analyzed the monetary benefit of adding infrared technology as an extension of the current drying process. In this way, we would be providing Pacific Can with enough information to consider both possibilities.

4.3.1. Replacing the Current Drying Process

To begin to analyze the complete replacement of the current drying process, we used the data given to the previous MQP by Pacific Can. Table 5 shows the costs associated with operating the drying oven used to dry the cans after they have been washed. The two different lines represent the two of the three production lines in the Beijing Pacific Can location we are directly focusing on. Table 6 represents these costs in U.S. dollars using the conversion rate on December 14, 2015 (Xe.com, 2015).

Current Process	**Daily Natural Gas Usage (.61 RMB per m^3)**	**Daily Cost in CNY**	**Annual Nat. Gas Usage (at 315 days)**	**Annual Costs in CNY**
Line 1	1,000	601	315,000	189,000
Line 2	900	549	283,500	172,935
Total	**1,900**	**1,150**	**598,500**	**361,935**

Table 5: Operational Cost of Oven in CNY



Cost of Current Process	**Conversion Rate***	**Production Lines**	**Daily Cost in USD**	**Annual Costs in USD**
Chinese Yuan (CNY)	**1**	Line 1	93.03	29,257.20
U.S. Dollar (USD)	**0.1548**	Line 2	84.99	26,770.34
		Total	**178.02**	**56,027.54**

*Conversion Rate (Dec. 14, 2015, XE.com)

Table 6: Operational Cost of Oven in USD

Using the information provided to us by the IR tube manufacturer, we analyzed the expected costs of operating a drying oven using IR tubes instead of natural gas. The information provided to us by the IR tube manufacturer, we analyzed the expected costs of operating a drying oven using IR tubes instead of natural gas. To do so we considered the data we gathered in addition to that recorded by the previous MQP team. The previous MQP team found that (on average) a single can would completely dry after 40 seconds inside their IR tube simulation. During our experiments, we tested how much water evaporated from a tray of 25 cans after 50 seconds – the amount of time cans currently spend inside the Natural gas powered oven. We found that the majority of all the cans were completely dry after 50 seconds. Therefore, for the purpose of the analysis, we considered the possibility that, if the current drying process is completely replaced using infrared technology, the cans should be dry in 40 seconds. Any amount of water that remains could be considered negligible as it would likely continue to evaporate as the cans continue down the conveyor belt.

Using 40 seconds as a guideline we continued with the analysis. As shown in the 3D model above in Figure 16, along the length it takes for the conveyor belt to move approximately 10 seconds, four sets of two infrared tubes are used to dry the cans. Hence, it would take 16 sets or 32 tubes to cover an area along which the conveyor belt would run the necessary 40 seconds. Making it 32 sets or 64 tubes for the two production lines. Table 7 reflects the expected costs of operating such a design.

To calculate how much it would cost to operate each tube, we referred to eBeijing.gov.cn, which provides general information and pricing guides for the Beijing area. For the analysis we used the rate charged to heavy industry power consumption customers using electricity at a level of about 35 Kilovolts. Moreover, we also took into consideration the 315 days during which the Beijing site operates.

Infrared Oven	**Daily Electricity Usage (0.5375 Yuan/KWH)**	**Annual Energy Consumption in CNY (at 315 days)**
1 Infrared tube (1,000 watts)	12.90	4,063.50
Line 1 (32 tubes)	412.80	130,032.00
Line 2 (32 tubes)	412.80	130,032.00
Total	826	260,064

Table 7: Operational Cost of infrared Oven in CNY

Cost of Infrared Ovens	**Conversion Rate***	**Production Lines**	**Daily Electricity Usage in USD**	**Annual Energy Consumption in USD (at 315 days)**
Chinese Yuan (CNY)	1	Line 1	63.90	20,128.95
U.S. Dollar (USD)	0.1548	Line2	63.90	20,128.95
		Total	127.80	40,257.91

*Conversion Rate (Dec. 14, 2015, XE.com)

Table 8: Operational Cost of Infrared Oven in USD

Certainly, one can see from the tables above that it would cost considerably less to operate an infrared oven. To emphasize this, we also calculated a Return on Investment (ROI). We found that the ROI on the replacement of the current drying process was a notable 36%. Table 9 shows the results of the ROI. Table 10 shows the costs of purchasing the IR tubes. Unfortunately, we were not able to find data on the materials that would be used to construct the heat containment box surrounding the area where the IR tubes would be installed, or information regarding the labor costs that would be incurred to install this design.

Return on Investment (ROI)	**Price in CNY**	**Price in USD**
Cost of Investment	266,416.00	41,241.20
Gain from Investment	361,935	56,027.54
ROI	36%	36%

Table 9: ROI on the Replacement of Current Drying Process

Initial/Annual Investment**	**Price in CNY**	**Price in USD***
Cost - Set of 2 infrared tubes	198.50	30.73
16 sets	3,176.00	491.64
Total for 32 Sets (2 Lines)	6,352.00	983.29
Total Annual cost (Energy + Cost)	266,416.0	41,241.20

*Conversion Rate (Dec. 14, 2015, XE.com) **Tube lifespan = 1 year

Table 10: Cost of Investment for Replacing the Current Drying Process

4.3.2 Infrared Technology as an Extension

The following analysis was that of implementing infrared technology to the existing drying process. Here, the intention would be to lower the temperature at which the natural gas powered oven currently operates. Thereby, lowering its operating costs. The design of such an addition would be that of the 3D model included above. In Table 11 below, we calculate the operating costs associated with running this model.

Infrared Oven	**Daily Electricity Usage (0.5375 Yuan/KWH)**	**Annual Energy Consumption in CNY (at 315 days)**
1 Infrared tube (1,000 watts)	12.90	4,063.50
Line 1 (8 tubes)	103.20	32,508.00
Line 2 (8 tubes)	103.20	32,508.00
Total	**206**	**65,016**

Table 11: Cost of Operating Infrared Addition

Infrared Ovens In U.S. Dollars	**Conversion***	**Production Line**	**Daily Electricity Usage in USD**	**Annual Energy Consumption in USD (at 315 days)**
Chinese Yuan (CNY)	**1**	Line 1	15.98	5,032.24
U.S. Dollar (USD)	**0.1548**	Line2	15.98	5,032.24
*Conversion Rate (Dec. 14, 2015, XE.com)		**Total**	**31.95**	**10,064.48**

Table *12*: Cost of Operating Infrared Addition in USD

Initial/Annual Investment**	**Price in CNY**	**Price in USD**
Cost - Set of 2 infrared tubes	198.50	30.73
4 sets	794.00	122.91
Total for 8 Sets (2 Lines)	**1,588.00**	**245.82**
Total Annual cost (Energy + Materials)	**66,604.0**	**10,310.30**

Table 13: Cost of Investment for Infrared Addition

As one can see on Table 13, the addition would only require 4 sets of two tubes. The cost of electricity remains the same as in the previous CBA. Table 9 shows the energy consumption for the 4 sets tubes used for each production line. To find a ROI, since we do not yet know exactly how much the current temperature could be lowered to, we hypothesized a 25% drop in energy consumption by the natural gas oven. This hypothesis based on the data we gathered during our experiments using our simulation. Therefore, the oven would consume 75% of the natural gas it currently uses. Table 14 reflects the cost of operating the current oven at 75% energy consumption.

Current Process at 75%	Daily Natural Gas Usage (.61 CNY per m^3)	Daily Cost in CNY	Annual Nat. Gas Usage (at 315 days)	Annual Costs in CNY
Line 1	800	451	252,000	141,750
Line 2	720	412	226,800	129,701
Total	**1,520**	**863**	**478,800**	**271,451**

Table 14: Operating Costs of Natural Gas Oven at 75%

For the ROI, we considered the cost of the investment, again to be the cost of operating the infrared tubes annually and the cost of the tubes themselves (estimated to last a year). The gain from this investment would be the current cost of operation. Using these parameters in the ROI formula, we get a return of 7%, as shown in Table 15. Furthermore, more experimenting with our design could lead to finding that less IR tubes are necessary to meet desired outcomes. Likewise, the temperature of the current process could be lowered so as to consume less than 25% of the energy it currently does.

Return on Investment (ROI)	Price in CNY	Price in USD
Cost of Investment	338,055.3	52,330.9527
Gain from Investment	361,935	56,027.54
ROI	7%	7%

Table 15: ROI for Infrared Addition

4.4 Sustainability Analysis for an Infrared Extension

1. Identify level and target of project landscape

The sustainability analysis was conducted at a local level. Only the implementation of infrared technology for the Beijing facility was taken into consideration. The target of the analysis was the use and disposal of the infrared tubes themselves. Essentially, this analysis was intended to find the feasibility of recycling the tubes and determining the sustainability of their power source.

1. Identify sustainability capabilities and relevant tools

Pacific Can has made commitment to the environment; Beijing is moving towards sustainability. Therefore, our innovative design should do the same.

According to our cost-benefit analysis, we can already see that the addition of the infrared tubes would indeed decrease the amount of energy necessary to operate the drying process. Similarly, lowering operating costs. Nonetheless, the source of this energy may not be as environmentally friendly. For this reason we researched how electricity is produced for the Beijing area. Additionally, with a lifespan of a year for each tube, steps should be taken to safely dispose of the tubes as they expire.

2. Report Findings

The energy supply used for making electricity has been a large concern for Beijing over the last few years. As a matter of fact, China uses approximately half of the world's coal to generate power. Contributing to China's status as the leading emitter of carbon dioxide (CO_2) in the world (The Big Story, 2015). Should this continue to be the case in China, it terms of maintaining a healthy carbon footprint, using the natural gas powered option may be the better option. In foresight, however, the infrared may still prove to be more sustainable.

China has issued an action plan to reduce the use of coal for generating electricity. The Chinese State Council released the Energy Development Strategy Action Plan in November 2014

(Nitkoski, 2015). This plan sets a goal to cut coal's share of total primary energy use to less than 62% by 2020. China is now moving towards using natural gas to generate electricity. Comparatively, using natural gas would emit between 0.6 – 2 pounds of CO_2 equivalent per kilowatt-hour (CO_2E/kWh) as opposed to coal, which emits between 1.4 – 3.6 pounds of CO_2E/kWh (Union of Concerned Scientists, 2015). As a result, the use of the benefits infrared tubes in our model would be further justified.

We found that the infrared tubes are recyclable to a certain extent. Each tube is made up of two different parts – the Quartz class casing and a nichrome (NiCr) wire (Infrared Heating Technologies, LLC, 2015). The glass is the most recyclable. Glasses like Quartz have a recyclability rate of 46% in the U.S. (pharosproject.net, n.d.). The second part is the NiCr wire inside of the Quartz glass casing. Due to its high tensile strength and resistance to corrosion, this wire is very recyclable as it may be refurbished and used again in other applications.

Lastly, as China continues to invest in more renewable energy, the use of the infrared system becomes more sustainable. Consequently, further following up on Pacific Can’s commitment to the environment. As the research and development continues on in the aluminum can manufacturing industry, more innovative solutions could be implemented to further improve the sustainability of the manufacturing as a whole. Likewise, more bright civil and environmental engineers continue to be trained in the concept of sustainability in engineering, opening the way to a more sustainable future in all fields.

5. Recommendations and Discussions

5.1 Project Accomplishment

The goal of this project was to assist Pacific Can in determining a more efficient and economical drying system into the manufacturing process of aluminum cans. We achieved this goal through the following objectives:

- Analyze the current process at Pacific Can
- Analyze the previous team's results and recommendations
- Perform experiments with larger quantity of sample cans
- Design a SolidWorks model of the improved process

These objectives were obtained through the methods that were used by our team. The current process at Pacific Can was analyzed through a tour of the Pacific Can facility where we were given the opportunity to an engineer questions about the current process. Through reading the previous team's report and speaking with our teammates from BUCT our team was able to analyze and understand what the results that were produced by the previous team along with their recommendations. Our team was able to perform experiments in a BUCT lab using a larger quantity of sample cans to create accurate data points to how the system would be used at the Pacific Can facility. A three dimensional model of the proposed system was created using the modeling software SolidWorks and given to Pacific Can to create a simulation of the manufacturing process. This simulation will be used to get the most accurate data possible for implementing an infrared drying system into the aluminum can drying process.

5.2 Recommendations

After completing the project our team compiled recommendations for Pacific Can. The recommendations for Pacific Can are what our team believes to be the best approach to continuing the project, ultimately implementing the infrared drying system in their manufacturing process. These recommendations include further experiments that the team believes should be done before implementing into the manufacturing system and how to turn the innovative idea of using infrared tubes to dry the aluminum cans into an entrepreneurial endeavor.

5.2.1. Experiments at Pacific Can with Simulation

Using our 3D model, Pacific Can will be able to create a simulation similar to the one that would be implemented into their drying process. The data gathered from experiments using this simulation would be a more accurate representation of how the new process would perform when implemented into the system. Experiments would be conducted similarly to those in the lab. Where, a larger quantity of cans (50 – 100 cans) would be weighed and placed on a conveyor belt. The cans would be sprayed with the amount of water solution as in the washing process. With the use of a conveyor belt, the cans can run above the infrared tubes. Afterwards, cans could be selected randomly or collected on a tray to record weight measurements. These same tests could then be performed using cans of different volumes (330 mL or 500 mL). Conducting these experiments multiple times and analyzing the data, would further determine the viability of the proposed drying process.

We would recommend recording different measurements. One measurement we were unable to record was temperature due to the lack of tools to do so correctly. Recording the temperature within the heat containment box or that of the cans as they come out may prove useful when determining a lower temperature for the oven. As the IR tubes heat up the cans, the oven does not have to work as hard to heat up the cans to quickly bring the water to boiling point. Therefore, a lower optimal temperature could be determined for operating the oven. Thereby, reducing the amount of energy the oven will consume.

An even lower temperature could be determined after testing using ME-50 and distilled water solution. According to the ME-50 manufacturers, mixing it with water will lower the boiling point of water, making it easier for the water on the cans to evaporate. Pacific Can already uses this solution in their current washing process. Running Tests using this solution and recording the temperature of the cans after they have passed above the IR tubes, Pacific Can could determine a much lower optimal temperature. Furthermore, we disregarded testing for an ideal distance at which the IR tubes themselves should be placed from each other.

In the manufacturing line the cans would pass above the IR tubes in a way we could not test in the lab. For this reason, we decided not to test for the best distance at which the IR tubes should be placed from one another. However, using the simulation this could be more precisely determined. Determining such a distance would also aid in identifying the number of IR tubes needed to suitably heat up the cans. Whilst, only using the required number of tubes and keeping energy consumption as low as possible. It is expected that the optimum distance for the IR tubes will be with them equally spaced across the width of the conveyer belt, as this will allow for the cans to have the most even exposure.

Another important data point that we believe should be found with the experiments at Pacific Can is the amount of time the cans would need to be in the system to become completely dry. This would allow the company to evaluate the cost of operating enough IR tubes to dry the cans completely versus the cost of operating the oven at a lower temperature with the IR tubes being used as a preliminary drying system. Another factor to take into account when deciding if replacing the current drying system completely with IR tubes would be to determine the amount of space needed for the IR tubes on the assembly line. If the length needed for exposure to the infrared tubes is longer than the space currently being used the current assembly line will need to be adjusted to create a longer area of conveyor belt for the cans to dry. This would cost the company a considerable amount of money to alter the current drying system completely.

After completing the recommended experiments, Pacific Can should then complete a cost benefit analysis of using the IR tubes in their drying process. A cost benefit analysis at this stage will ultimately determine whether investing in the infrared drying system is a good business decision financially. This cost benefit analysis should focus on the two options for the infrared system, use the system to supplement the current drying process or use the system to replace the current drying process. While doing the analysis of supplementing the drying process the information of the most efficient spacing of the IR tubes and the measured temperature of the cans as they exit the infrared system will be critical. The spacing of the tubes will allow the company to determine the amount of IR tubes needed for the system. Knowing the temperature of the tubes when they exit the infrared system will allow the company to calculate what temperature the current oven will need to operate at with the infrared system before it. In order to replace the current drying process Pacific Can should calculate the distance between groupings of the infrared tubes. This information will allow the company to know the amount of space needed to dry the cans and how many IR tubes will be needed to completely dry the cans.

5.2.2 Waterproof Infrared Tubes

Engineers at Pacific Can expressed concern over the fact that once washed cans enter the drying process with infrared tubes; some of the solution may drip on the IR tubes. After conducting some research we found that waterproof IR tubes are readily available in the market - Aibaba being one of the primary retailers, selling such tubes that cost between CNY 60 and 360. We highly recommend that waterproof tubes be purchased to make sure that the functionality of the tubes isn't compromised.

5.3 Innovation and Entrepreneurship in Our Project

A truly innovative idea could be used and applied, with a bit of ingenuity, in areas for which it may not have been directly intended. After touring Pacific Can we realized that the cans enter another drying oven after they are decorated with paint. Thus, it may be possible, to implement IR tubes to this drying process so as to further decrease energy consumption of the entire process. If we zoom out a little further, the IR tubes could be installed to other manufacturing lines within the Beijing facility. Even a little further out, although their equipment may differ, it is possible for IR tubes to be installed in other Pacific Can locations throughout China. Similarly, Aluminum can manufacturers in China as well as other countries could apply this into their facilities.

Our design for the IR tubes itself could also be improved upon or even replaced by a more effective and economically beneficial idea. One could find a different layout of the IR tubes that may work better than the current one. Perhaps IR tubes that consume much less energy and provide the same effect could be developed later down the road. Similarly, stronger, more sustainable tubes could be developed. In which case, the number of tubes required to adequately heat the cans could decrease along with energy consumption costs. It is even possible that another MQP team could find an innovative solution that could prove even more effective the one we investigated. That is what innovation and entrepreneurship is all about – enhancing and reducing waste.

5.4 Constraints and Future Studies

Throughout our time in Beijing our team has come across multiple constraints in our project. These constraints affected our project timeline and created obstacles for the team. The first constraint that the team faced was that our project advisors were unable to join us in Beijing. This made it difficult to update the advisors with progress reports and to communicate any issues that the team was having with the project. This also created difficulty in acquiring feedback on work that had been accomplished. It also made it difficult expressing the objectives of our project as a MQP to the BUCT advisor.

The second constraint that faced the team was the language barrier. None of the WPI students were able to speak Chinese, which made it difficult at times to communicate with BUCT students and the BUCT advisor. Local data was also difficult to acquire due to web pages being in Chinese. While we had Google Translate and other language translators, they didn't always work properly and many times the translations did not make sense when read. This also affected the ability to acquire materials needed for the experiments at the BUCT lab. It was difficult to communicate to Professor Li of BUCT what materials were needed and why they were needed. It also then made it difficult for the students to find the needed materials. The language barrier also affected the communication with the engineers at Pacific Can. When the team visited the facility Professor Liang had to translate all interactions with the employees for the students.

The third constraint that we faced was that only one team member had access to SolidWorks during our time in Beijing. This restricted the amount of SolidWorks parts that could be worked on at a time to one. Due to only one person being able to work on the 3D model for the simulation it took longer to create than expected. The SolidWorks program was only accessible while Internet was available because the license from WPI needed to be accessed through the WPI VPN.

The fourth constraint in our project was the Internet. The Wi-Fi on the BUCT campus is very unreliable outside of the dorm. The Internet was difficult to connect to and when we were able to connect it was extremely spotty and many times didn't work. The Wi-Fi in the dorm rooms was more reliable but would become very slow at times and stopped working several times over the seven-week period. The unreliable Internet also affected the third constraint of SolidWorks. Due to the unreliable Internet only one member of the team had access to SolidWorks and occasionally none of the team members were able to access the program. The students who didn't have access to SolidWorks were unable to remote desktop from their computers to the WPI server to access the program either due to the slow Internet speeds and the unreliable connection.

The fifth constraint would be the amount of time for the project. Due to the seven week term the team was unable to accomplish everything that we originally intended. The time restraint was to short to be able to have Pacific Can construct the simulation experiment that we had planned on using. Due to this the team was not able to gather as much data as initially planned.

The sixth constraint that our team faced was the difficulty of gaining access to the lab and lab equipment. Due to us not being BUCT students the manager of the lab that our materials were stored would not give us the keys to the lab and would only give it to our BUCT partners. It was difficult finding times that our BUCT teammate with the key was able to join us due to the work they had in classes. It was also difficult finding access to a lab that had a molecular scale in it in order to run our experiments because the lab that our materials were located in did not have a scale. We also were not able to use the solution that is used in the washing system in our experiment because we were not able to acquire the solution. Tap water was used instead.

The seventh constraint that our team faced was the location that our team was in respect to the location of the Pacific Can facility. From our location it was difficult to reach the facility, as it was not easy to get there through public transportation. The difficulty in getting to the facility further affected our communication with the facility in understanding what the company desired of the team.

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Appendices

Appendix A

Instructions for Constructing Experiment Setup

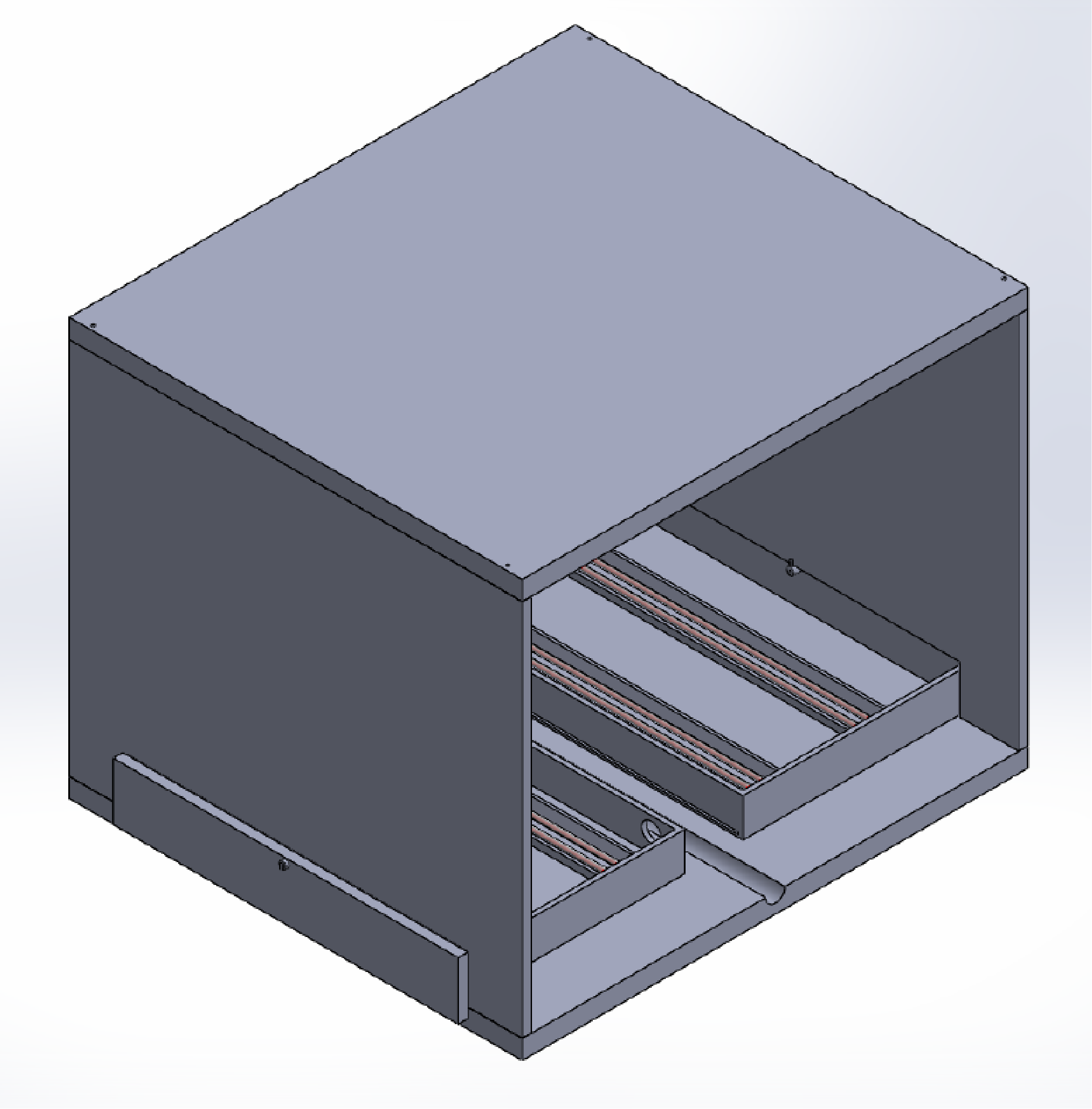
Parts List:

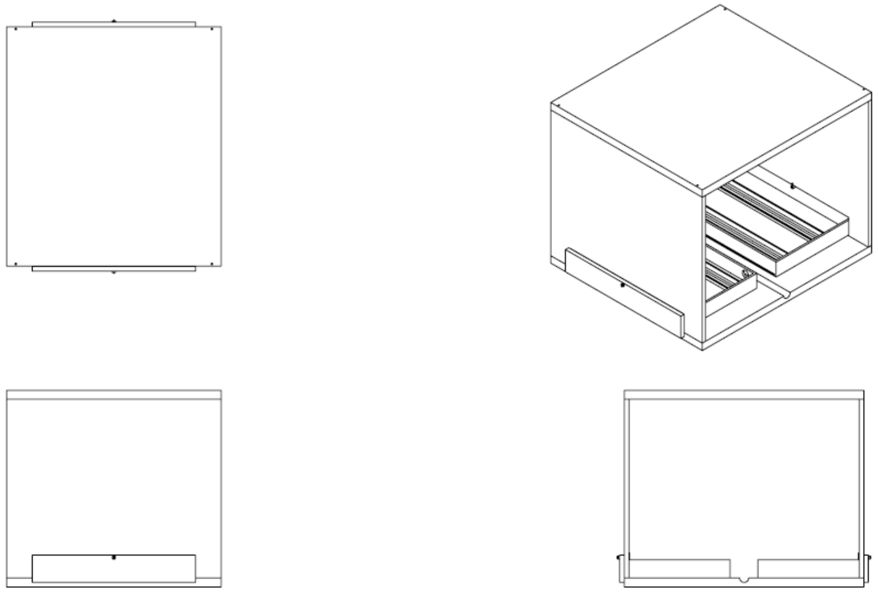
- #5 Binding Head Machine Screw – 8x
- #00 Binding Head Machine Screw- 2x
- Drawers – 2x
- Lock Part 1 – 2x
- Lock Part 2 – 2x
- Box Side – 2x
- Box Bottom – 1x
- Box Top – 1x
- Infrared Tubes – 8x (subject to change)
- Infrared Tube Casings – 4x (Subject to change)

Assembly

- Using 4 of the #5 Binding Head Machine Screws attach the two Box Sides to the Box Bottom.

- Using 4 of the #5 Binding Head Machine Screws attach the Box Top to the 2 Box Sides.
- Take the 1 Drawer and slide 1 Lock Part 1 into the hole in the center of the front of the drawer.
- Attach 1 Lock Part 2 to the Lock Part 1 in the Drawer by fitting the cutout in the Lock Part 1 with the outcrop in the Lock Part 2. Use 1 #00 Binding Head Machine Screw to attach them.
- Repeat last step with left over Drawer, Lock Part 1, Lock Part 2 and #00 Binding Head Machine Screw.
- Insert Drawers into the cutouts in the Box Sides.
- Insert Infrared Tubes into the Infrared Tube Casings.
- Insert Infrared Tube Casings into the Drawers evenly spaced, parallel with the Box Sides.
- The Top of the Conveyer Belt should run through the Box and the Bottom of the Conveyer Belt should run Bellow the Box.
    - The Conveyer belt should be the same width as the conveyer belt in the assembly line. (1.29m), and should be either 2m or 3m long.





NEXT ASSY | USED ON

APPLICATION

UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTERMETERS
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Andrew Kenyon	12/4/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

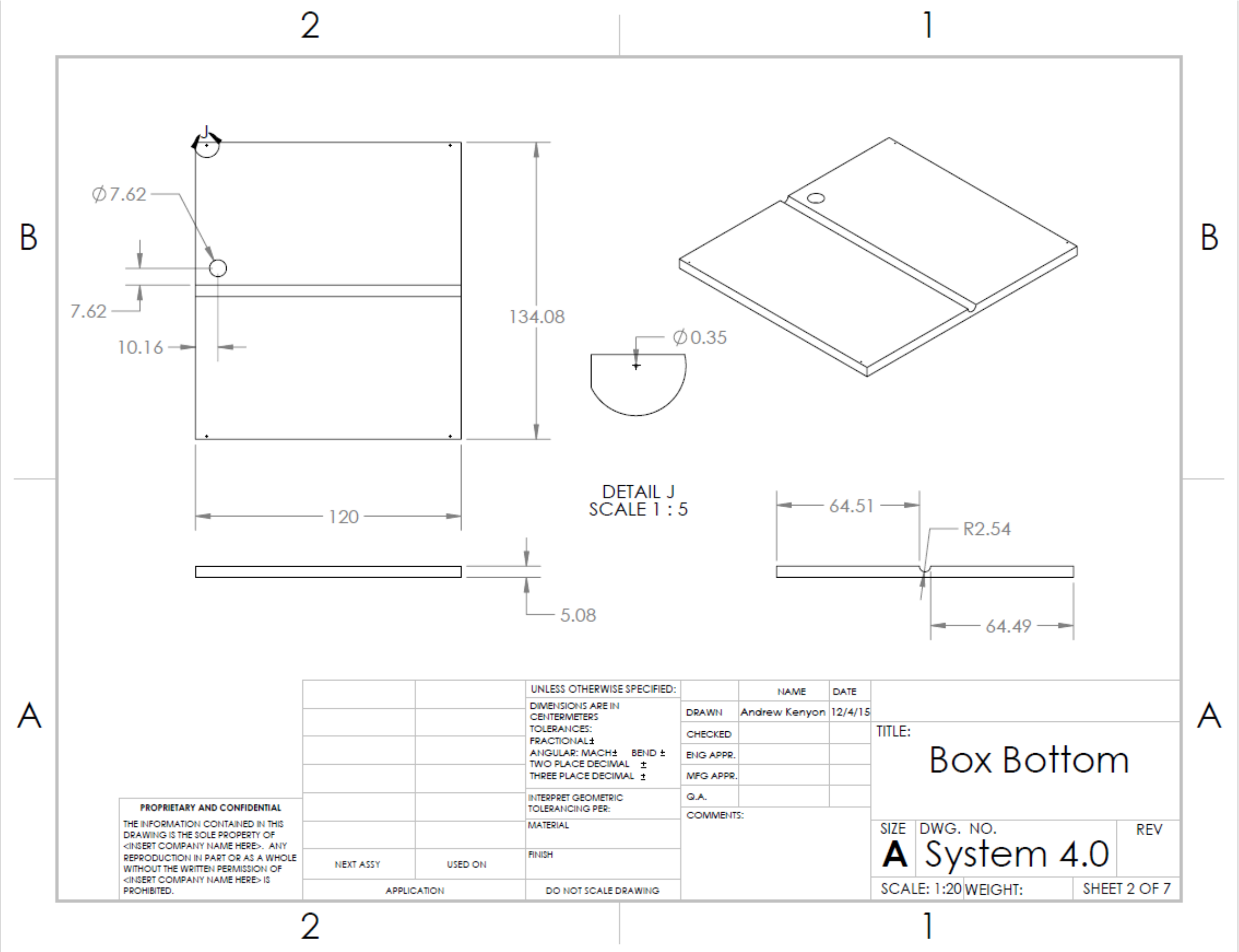
COMMENTS:

TITLE:

Full Assembly

SIZE **A** DWG. NO. System 4.0 REV

SCALE: 1:25 WEIGHT: SHEET 1 OF 7



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTERMETERS
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

NEXT ASSY
USED ON
APPLICATION

	NAME	DATE
DRAWN	Andrew Kenyon	12/4/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Box Bottom

SIZE A
DWG. NO. System 4.0
REV

SCALE: 1:20 WEIGHT: SHEET 2 OF 7

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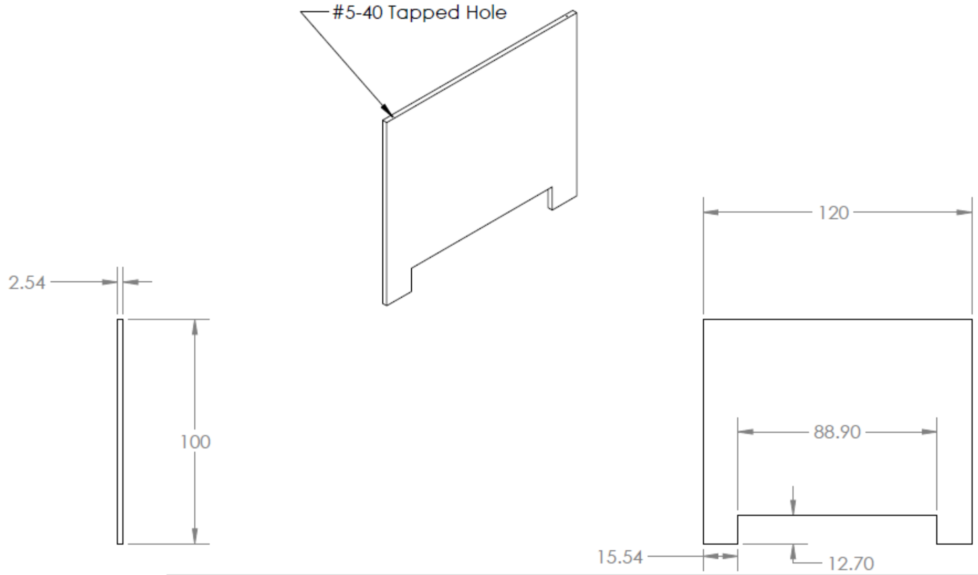

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TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH

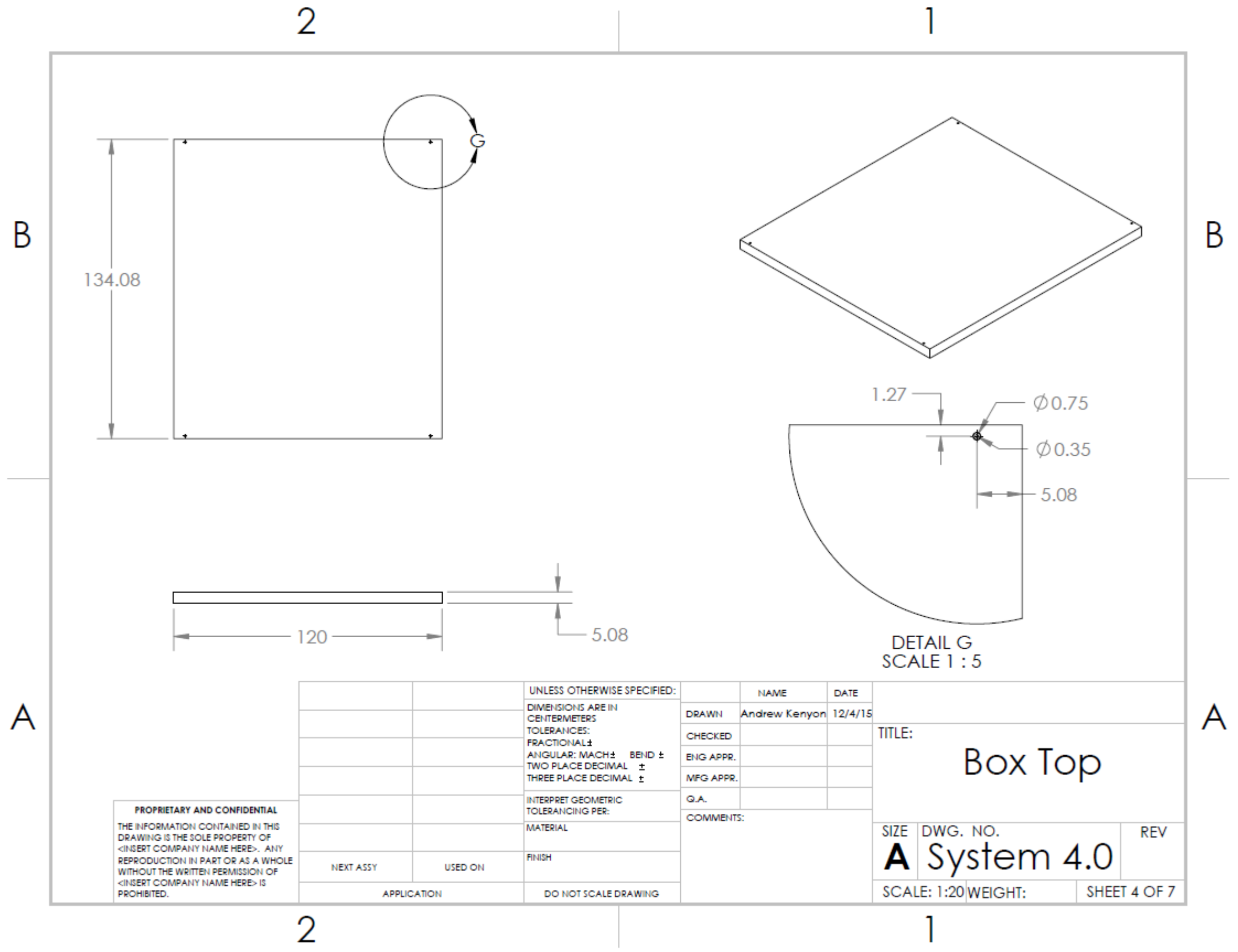
NEXT ASSY
USED ON
APPLICATION
DO NOT SCALE DRAWING

	NAME	DATE
DRAWN	Andrew Kenyon	12/4/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Box Side

SIZE A
DWG. NO. System 4.0
REV
SCALE: 1:20
WEIGHT:
SHEET 3 OF 7



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TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

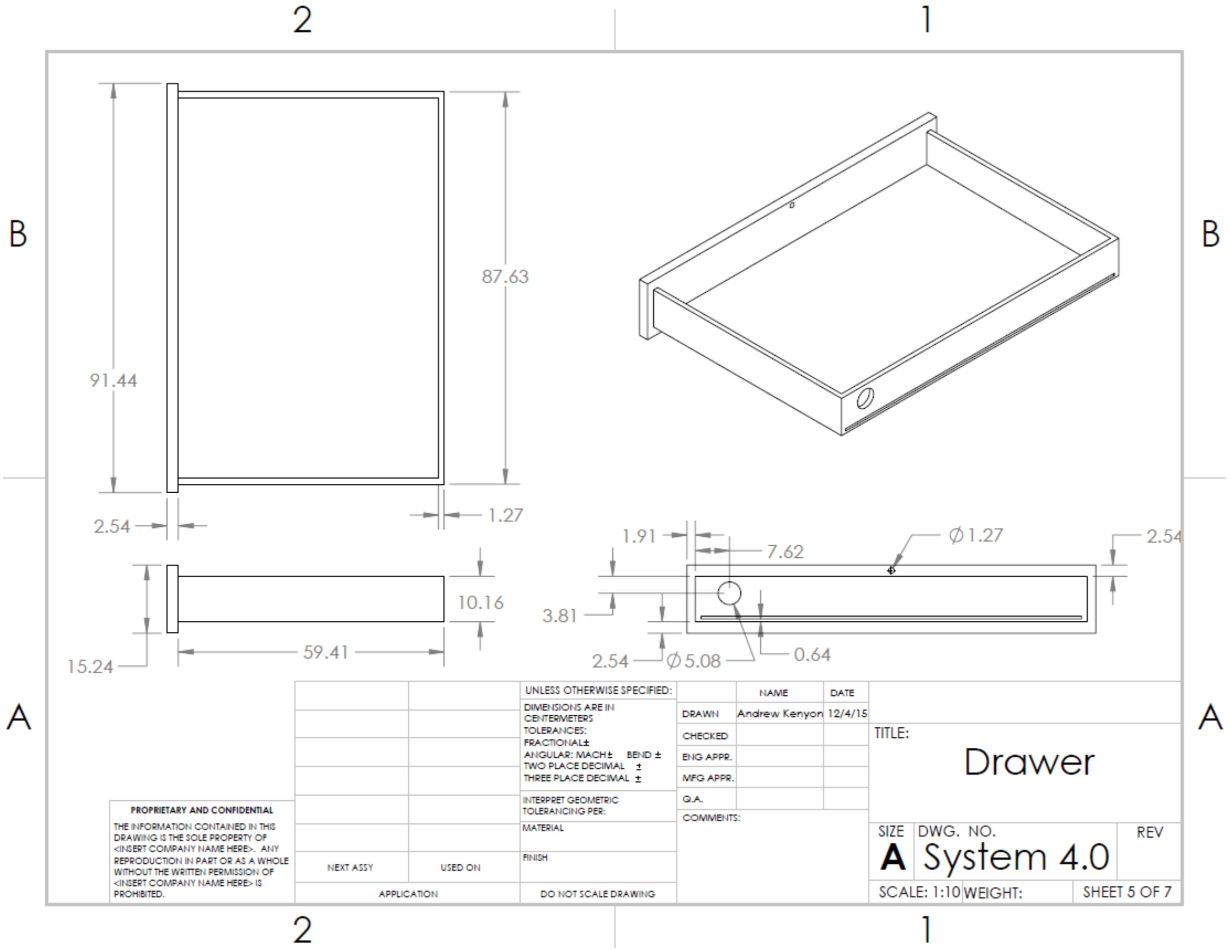
	NAME	DATE
DRAWN	Andrew Kenyon	12/4/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE: Box Top

SIZE A
DWG. NO. System 4.0
REV

SCALE: 1:20
WEIGHT:
SHEET 4 OF 7



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTERMETERS
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING

NEXT ASSY
USED ON
APPLICATION

	NAME	DATE
DRAWN	Andrew Kenyon	12/4/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE:
Drawer

SIZE A
DWG. NO. System 4.0
REV
SCALE: 1:10
WEIGHT:
SHEET 5 OF 7

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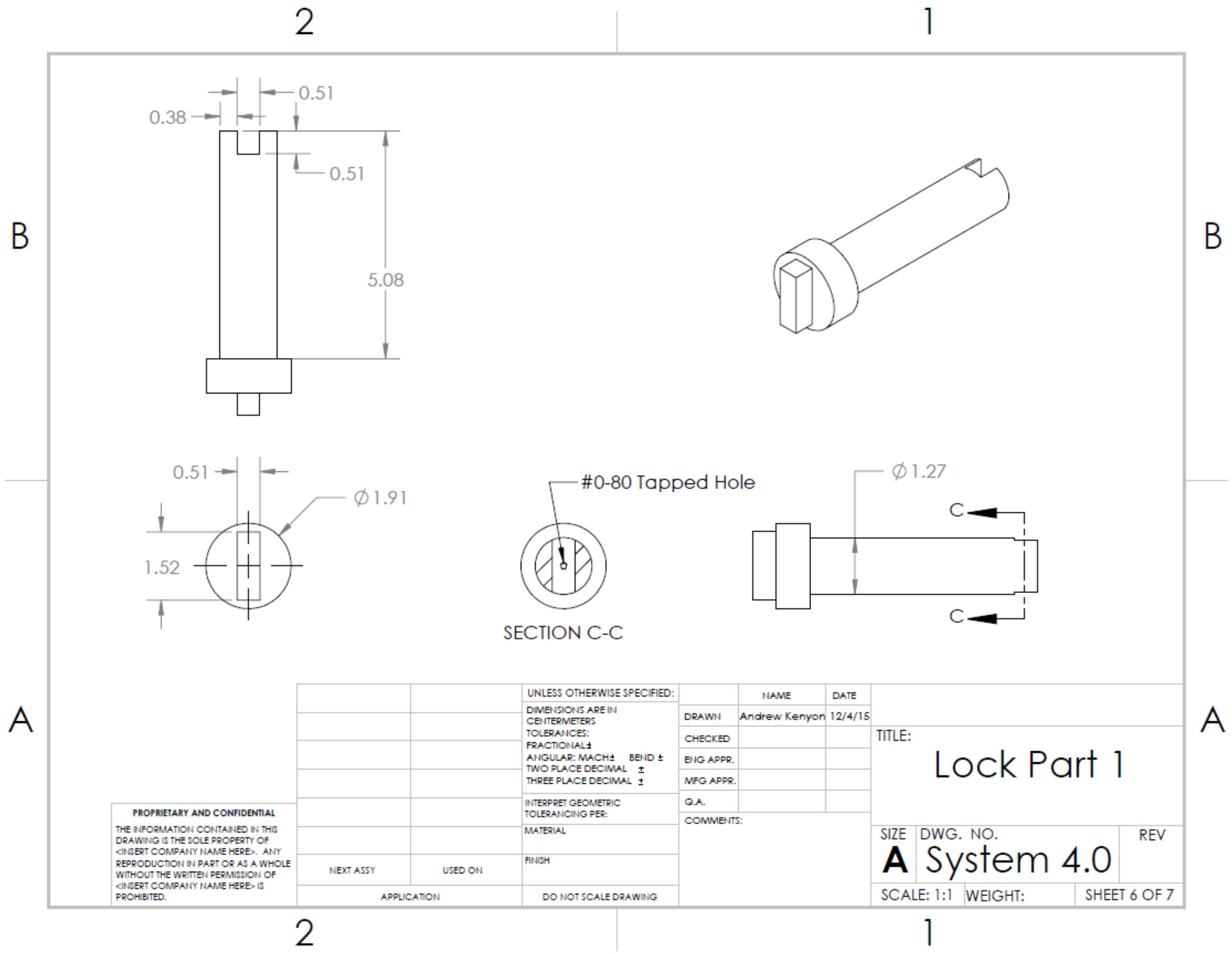
2
1
B
A
0.51
0.38
0.51
5.08
0.51
⌀1.91
1.52
#0-80 Tapped Hole
SECTION C-C
⌀1.27
C
C
UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTERMETERS
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±
INTERPRET GEOMETRIC TOLERANCING PER:
MATERIAL
FINISH
DO NOT SCALE DRAWING
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APPLICATION
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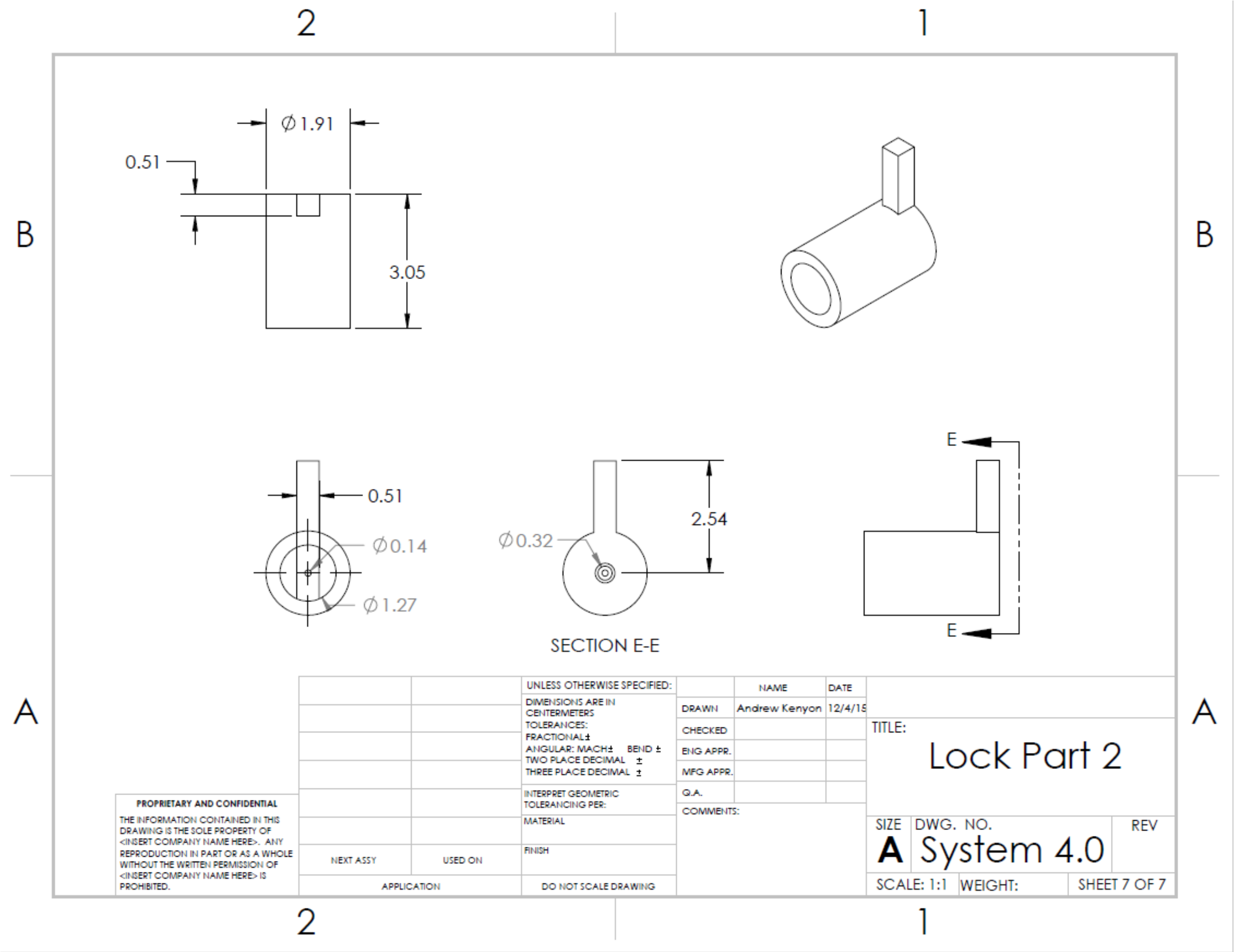
NAME
DATE
DRAWN
Andrew Kenyon
12/4/15
CHECKED
ENG APPR.
MFG APPR.
Q.A.
COMMENTS:
TITLE:
Lock Part 1
SIZE
A
DWG. NO.
System 4.0
REV
SCALE: 1:1
WEIGHT:
SHEET 6 OF 7



UNLESS OTHERWISE SPECIFIED:
DIMENSIONS ARE IN CENTERMETERS
TOLERANCES:
FRACTIONAL±
ANGULAR: MACH± BEND ±
TWO PLACE DECIMAL ±
THREE PLACE DECIMAL ±

INTERPRET GEOMETRIC TOLERANCING PER:

MATERIAL

FINISH

DO NOT SCALE DRAWING

NEXT ASSY

USED ON

APPLICATION

	NAME	DATE
DRAWN	Andrew Kenyon	12/4/15
CHECKED		
ENG APPR.		
MFG APPR.		
Q.A.		

COMMENTS:

TITLE: Lock Part 2

SIZE A

DWG. NO. System 4.0

REV

SCALE: 1:1

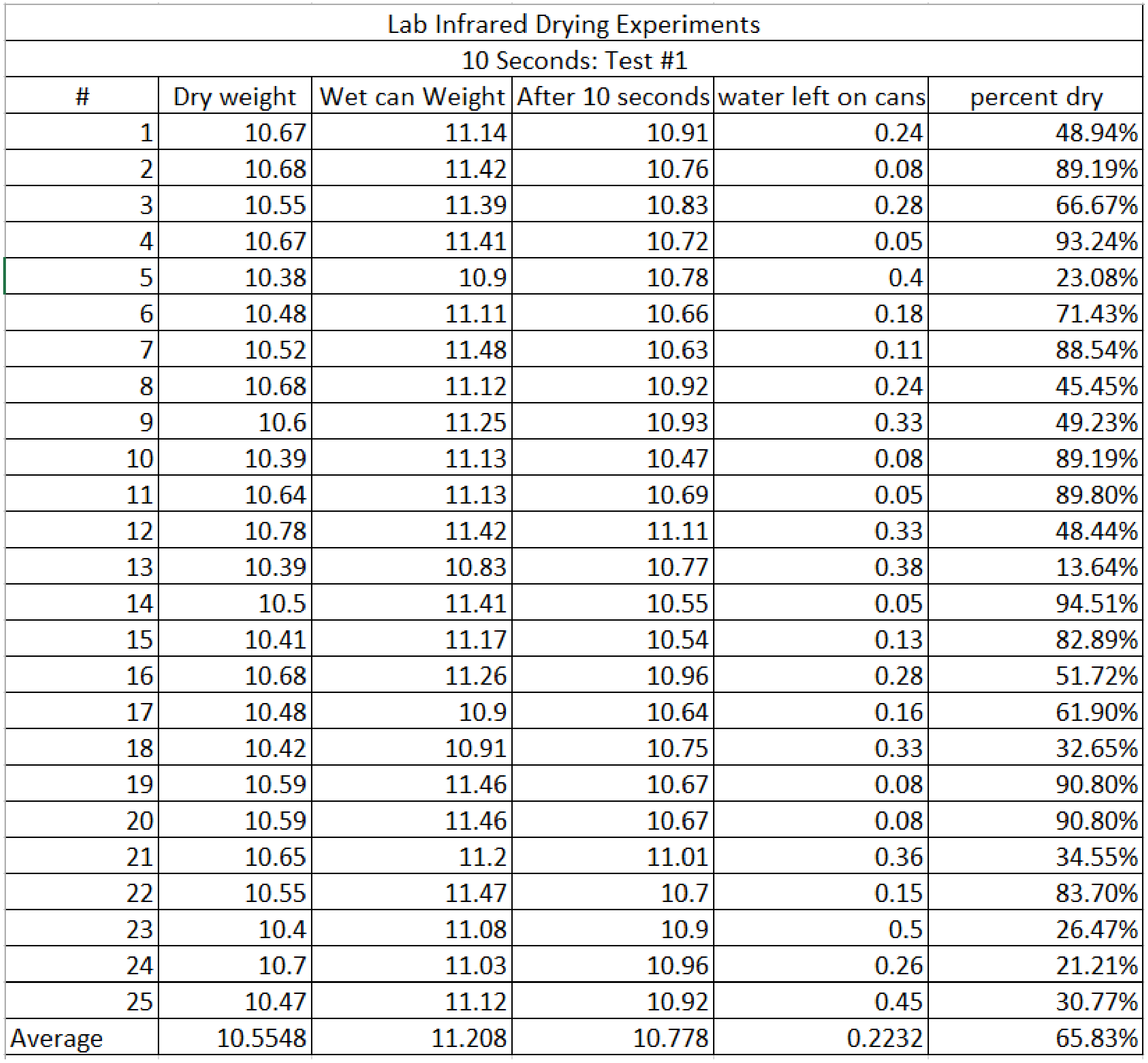
WEIGHT:

SHEET 7 OF 7

PROPRIETARY AND CONFIDENTIAL

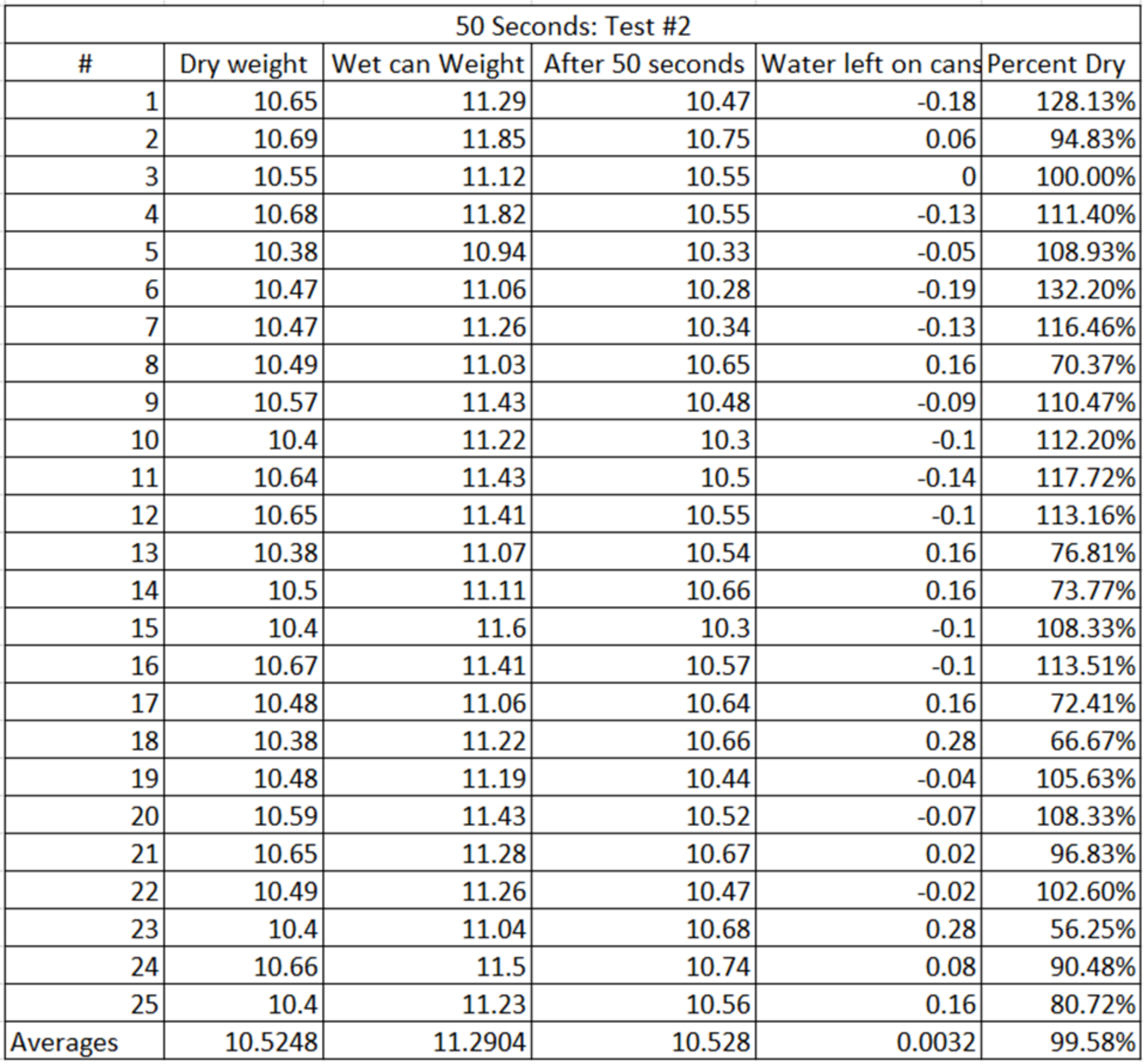
Appendix B

Data from Experiments



Lab Infrared Drying Experiments					
10 Seconds: Test #1					
#	Dry weight	Wet can Weight	After 10 seconds	water left on cans	percent dry
1	10.67	11.14	10.91	0.24	48.94%
2	10.68	11.42	10.76	0.08	89.19%
3	10.55	11.39	10.83	0.28	66.67%
4	10.67	11.41	10.72	0.05	93.24%
5	10.38	10.9	10.78	0.4	23.08%
6	10.48	11.11	10.66	0.18	71.43%
7	10.52	11.48	10.63	0.11	88.54%
8	10.68	11.12	10.92	0.24	45.45%
9	10.6	11.25	10.93	0.33	49.23%
10	10.39	11.13	10.47	0.08	89.19%
11	10.64	11.13	10.69	0.05	89.80%
12	10.78	11.42	11.11	0.33	48.44%
13	10.39	10.83	10.77	0.38	13.64%
14	10.5	11.41	10.55	0.05	94.51%
15	10.41	11.17	10.54	0.13	82.89%
16	10.68	11.26	10.96	0.28	51.72%
17	10.48	10.9	10.64	0.16	61.90%
18	10.42	10.91	10.75	0.33	32.65%
19	10.59	11.46	10.67	0.08	90.80%
20	10.59	11.46	10.67	0.08	90.80%
21	10.65	11.2	11.01	0.36	34.55%
22	10.55	11.47	10.7	0.15	83.70%
23	10.4	11.08	10.9	0.5	26.47%
24	10.7	11.03	10.96	0.26	21.21%
25	10.47	11.12	10.92	0.45	30.77%
Average	10.5548	11.208	10.778	0.2232	65.83%

50 Seconds: Test #2					
#	Dry weight	Wet can Weight	After 50 seconds	Water left on cans	Percent Dry
1	10.65	11.29	10.47	-0.18	128.13%
2	10.69	11.85	10.75	0.06	94.83%
3	10.55	11.12	10.55	0	100.00%
4	10.68	11.82	10.55	-0.13	111.40%
5	10.38	10.94	10.33	-0.05	108.93%
6	10.47	11.06	10.28	-0.19	132.20%
7	10.47	11.26	10.34	-0.13	116.46%
8	10.49	11.03	10.65	0.16	70.37%
9	10.57	11.43	10.48	-0.09	110.47%
10	10.4	11.22	10.3	-0.1	112.20%
11	10.64	11.43	10.5	-0.14	117.72%
12	10.65	11.41	10.55	-0.1	113.16%
13	10.38	11.07	10.54	0.16	76.81%
14	10.5	11.11	10.66	0.16	73.77%
15	10.4	11.6	10.3	-0.1	108.33%
16	10.67	11.41	10.57	-0.1	113.51%
17	10.48	11.06	10.64	0.16	72.41%
18	10.38	11.22	10.66	0.28	66.67%
19	10.48	11.19	10.44	-0.04	105.63%
20	10.59	11.43	10.52	-0.07	108.33%
21	10.65	11.28	10.67	0.02	96.83%
22	10.49	11.26	10.47	-0.02	102.60%
23	10.4	11.04	10.68	0.28	56.25%
24	10.66	11.5	10.74	0.08	90.48%
25	10.4	11.23	10.56	0.16	80.72%
Averages	10.5248	11.2904	10.528	0.0032	99.58%



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#	Dry weight	Wet can Weight	After 50 seconds	Water left on cans	Percent Dry
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6	10.47	11.06	10.28	-0.19	132.20%
7	10.47	11.26	10.34	-0.13	116.46%
8	10.49	11.03	10.65	0.16	70.37%
9	10.57	11.43	10.48	-0.09	110.47%
10	10.4	11.22	10.3	-0.1	112.20%
11	10.64	11.43	10.5	-0.14	117.72%
12	10.65	11.41	10.55	-0.1	113.16%
13	10.38	11.07	10.54	0.16	76.81%
14	10.5	11.11	10.66	0.16	73.77%
15	10.4	11.6	10.3	-0.1	108.33%
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17	10.48	11.06	10.64	0.16	72.41%
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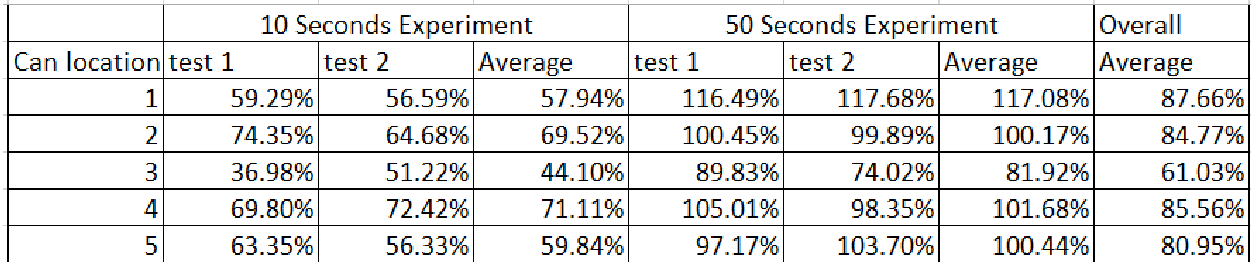
19	10.48	11.19	10.44	-0.04	105.63%
20	10.59	11.43	10.52	-0.07	108.33%
21	10.65	11.28	10.67	0.02	96.83%
22	10.49	11.26	10.47	-0.02	102.60%
23	10.4	11.04	10.68	0.28	56.25%
24	10.66	11.5	10.74	0.08	90.48%
25	10.4	11.23	10.56	0.16	80.72%
Averages	10.5248	11.2904	10.528	0.0032	99.58%



	10 Seconds Experiment			50 Seconds Experiment			Overall
Can location	test 1	test 2	Average	test 1	test 2	Average	Average
1	59.29%	56.59%	57.94%	116.49%	117.68%	117.08%	87.66%
2	74.35%	64.68%	69.52%	100.45%	99.89%	100.17%	84.77%
3	36.98%	51.22%	44.10%	89.83%	74.02%	81.92%	61.03%
4	69.80%	72.42%	71.11%	105.01%	98.35%	101.68%	85.56%
5	63.35%	56.33%	59.84%	97.17%	103.70%	100.44%	80.95%