Design of a 300 Kilogram Coffee Roaster

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**Mission Statement**

Roasting Innovations mission is to develop a 300 kilogram roaster that will be safe and reliable with the ability to be easily reproduced. The team will accomplish this by redesigning the drum and drive train components of the roaster. Materials used to build the roaster will be chosen to maintain optimal quality of the product being roasted.

The business plan will outline the economic prospects of the 300 kilogram roaster. Roasting Innovation will define and expand the market for an industrial sized roaster while remaining in the middle of the price market for similar products. Communication with the sponsor will be maintained throughout the entire designing and building process to be sure the team produces an optimal product. Communication with customers will be maintained through a series of surveys to evaluate satisfaction with the current product, as well as what changes they would suggest.

**Problem Statement**

Roasting Innovation needs to design and produce a drum and drive train for a 300 kilogram roaster that can withstand temperatures up to approximately 600°F so as to reduce destruction of the quality of the roaster due to thermal expansion. The 300 kilogram roaster needs to be able to roast exceptional coffee to the user’s taste, be easily reproducible, and remain safe to operate.
Statement of Work

Scope

Roasting Innovation will complete the design, construction and marketing of a 300 kilogram roaster for US RoasterCorp. Our work will include the construction of the drive train and the rotating drum, which will withstand heating up to 600°F for roasting of 300 kilograms of coffee beans and prevent compromising the operating of the roaster. It will also include the marketing and promotion of the 300 kilogram industrial roaster to the company’s future and current customers.

Location

The work for Roasting Innovation will be done mostly on the Oklahoma State University campus within the computer laboratories provided by the Biosystems and Agricultural Engineering department as well as the Agricultural Communications department. These labs include computer labs as well as machine shops where we will build and test different drums for the roaster. There will also be some machine work done by our client, US RoasterCorp, in Oklahoma City.

Time Period

The design process for the 300 kilogram industrial coffee roaster began in late August of 2010 and the final product will be completed by April 22, 2011.
Schedule of Deliverables

Table 1: Schedule of Deliverable

<table>
<thead>
<tr>
<th>Deliverable</th>
<th>Due Date</th>
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<tbody>
<tr>
<td>Mission Statement</td>
<td>September 27, 2010</td>
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<td>Problem Statement</td>
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<td>Detailed Report and Budget</td>
<td>October 18, 2010</td>
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<tr>
<td>Competitive Analysis, Research, and Investigation</td>
<td>October 22, 2010</td>
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<tr>
<td>Statement of Work</td>
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<td>December 15, 2010</td>
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<td>Acceptance of Final Design</td>
<td>December 17, 2010</td>
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<tr>
<td>First Prototype Completed</td>
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<tr>
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<td>March 14, 2011</td>
</tr>
<tr>
<td>Final Design Completed</td>
<td>March 21, 2011</td>
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<tr>
<td>Final Report</td>
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</tr>
<tr>
<td>Final Presentation</td>
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Standards

According to the Specialty Coffee Association of America (SCAA) when evaluating green coffee beans (unroasted) there are two grades, premium and specialty. Specialty green coffee beans should have a minimum of five secondary full defects. Secondary defects are imperfections in the hull/husk or shell of the bean and can be caused by insect and water
damage. Other secondary defects include partially black, partially sour, or floating beans, and if the bean samples contain small or sticks. The green coffee beans should have no more than 10-12% moisture content. The roasted coffee beans should also meet the SCAA’s cup evaluation of 80 points or above. Points are earned using a SCAA standard 16 point scale which evaluates cups of coffee based on fragrance and aroma, flavor, aftertaste, acidity, body, balance, uniformity, clean cup, sweetness, defects, and overall. Roasted coffee beans should be roasted 8 to 24 hours of cupping. The entire roasting time for the coffee beans must be between eight and twelve minutes and should exclude scorching and tipping of the beans. Once the roasted coffee beans reach room temperature they should be sealed in air tight containers until it is time for them to be cupped.

Coffee roasters should be operated at maximum temperatures ranging between 370°F and 1000°C depending on the size of the load, and the beans are roasted for a period of time ranging from eight to twelve minutes. Roasters are typically horizontal rotating drums that tumble the coffee beans in a current of hot air. The coffee roasters usually operate a batch mode, but sometimes operate as continuous systems. The air inside of the roaster is heated either by a direct flame applied on the outside of the roaster or indirectly using a heater to pre-heat the air before it is circulated through the drum.

Particulate matter, volatile organic compounds, organic acids, and combustion products are the principle emissions from coffee processing. Particulate matter emissions from the receiving, storage, cleaning, roasting, cooling, and stoning operations are typically ducted to cyclones before being emitted into the atmosphere. Gaseous emissions from roasting
operations are typically ducted to a thermal oxidizer following particulate matter removal. Some facilities use burners as thermal oxidizers to heat the roaster; however, separate thermal oxidizers are more efficient because the desired operating temperature is typically between 650°C and 816°C (1200°F and 1500°F), which is 93°C to 260°C (200°F to 500°F) more than the maximum temperature of most roasters. Emissions from spray dryers are typically controlled by a cyclone, which is used to cool emissions, followed by a wet scrubber, which removed particulates from exhaust.

Acceptance

To be considered acceptable, the 300 kilogram roaster should be able to roast at least 300 kilograms of coffee beans within eight to twelve minutes at the standard temperature, about 500°F. The roaster should be able to do this with minimal safety risks. If the roaster contains excessive heat escape, hot spots, loose connections, or excessive pressure buildup it will be considered unacceptable. The aesthetic design should resemble the previously design roasters developed by US RoasterCorp but may be altered with the consent of both US RoasterCorp and Roasting Innovation in order to improve overall appearance. The coffee roaster must also meet all necessary industry standards.

Special Requirements

The first unique consideration is taste. Our group must consider the taste of the coffee beans after they come out of the roaster. Another requirement to which we must pay attention to is the relatively high temperatures. Our roaster will reach temperatures around 400 degrees Celsius for about 15 minutes. Fifteen minutes is the approximate roasting time for coffee beans
to obtain the desired specialty roast. The next special requirement to be considered is the ability of the roaster to mix the beans thoroughly. This must be accomplished while also allowing for quick evacuation of the beans to prevent over cooking. We must also know how the heating elements will affect the steel. The heating of the barrel will cause thermal expansion to occur and must be compensated for. If the expansion problem is not solved, the roaster might lose beans and the efficiency will decrease. Another requirement is noise. Our team will be evaluating different kinds of gears to decrease the noise. As is, the existing roasters make quite a bit of noise with their straight cut gears. Lastly, our team must follow air pollution standards in not only Oklahoma but the entire nation, specifically southern California, where the regulations are much greater than the rest of the nation.

**Task List**

The following is a list of all tasks to be completed in order to define a final design for the 300 kilogram industrial coffee roaster. It encompasses all engineering, marketing, and economic tasks which Roasting Innovation will accomplish by the completion of this project.

**Engineering**

1. Calculate the volume and thermal expansion of the drum
2. Perform Tests: Mixing, Fin, Inlet, Outlet, Uniform Heating, Pressure, Airflow, and Anaerobic Conditions/Taste
3. Determine speed and horsepower requirements
4. Size mechanical equipment: gears, bearings
Communications

1. Website
2. Brochure
4. Specifications Sheet

Economics

1. Write a Product Plan
2. Competitive Analysis
3. Market Analysis

**Work Breakdown Structure**

1. **300 Kilogram Coffee Roaster**

   1.1 Drum

      1.1.1 *Calculate Dimensions*
      
      1.1.1.1 Volume
      
      1.1.1.2 Thermal Expansion

      1.1.2 *Fin Design*
      
      1.1.2.1 Mixing Tests

      1.1.3 *Inlet and Outlet*
      
      1.1.3.1 Efficiency
      
      1.1.3.2 Speed
1.1.4 Material

1.1.4.1 Safety Factor

1.2 Drive Train

1.2.1 Bearings

1.2.1.1 Size Bearings

1.2.2 Gear Set

1.2.2.1 Size Gears

1.2.3 Motor

1.2.3.1 Power Requirement

1.2.3.2 RPM Requirement

1.3 Marketing

1.3.1 Website

1.3.1.1 Design

1.3.2 Brochure

1.3.2.1 Photos

1.3.2.2 Information about Product

1.3.2.3 Design

1.3.2.4 Printing

1.3.3 Promotional Index Card

1.3.3.1 Information about Product

1.3.3.2 Design

1.3.3.3 Printing

1.3.4 Pictorial User Manual

1.3.4.1 Photos
1.3.4.2 Information on Product Use
1.3.4.3 Design
1.3.4.4 Printing
1.3.4.5 Binding

1.4 Business

1.4.1 Executive Summary
1.4.1.1 Objectives
1.4.1.2 Mission
1.4.1.3 Keys to Success

1.4.2 Company Description
1.4.2.1 Company Locations

1.4.3 Product
1.4.3.1 Description
1.4.3.2 Competitive Comparison
1.4.3.3 Sales Literature

1.4.4 Financial Analysis
1.4.4.1 Financial Indicators
1.4.4.2 Break Even Analysis

**Market Research**

**Introduction**

Roasting Innovation has completed a competitive analysis of the coffee industry as part of our research for the development of the 300 kilogram coffee roaster. Within our analysis,
Roasting Innovation discussed and addressed the issues of the industry analysis, technical analysis, customers and buyers of the product, competitors and their resources, and the client company as well as its resources. The analysis also shows many different patents that will be useful in the designing of the drum, as well as different marketing techniques that could be useful. Overall, the analysis shows the depth of the coffee industry and the variety of areas that could affect the project.

**Patents**

**Coffee Roasting Apparatus and Method** – Patent 7143686 describes an industry coffee roaster that includes a combustion chamber and roasting drum. The heating gases for the coffee beans recirculate through the combustion chamber to remove the coffee bean chaff. Patent 7143686 is applicable to Roasting Innovation’s design because it represents an alternative roasting drum design.

**Coffee Roaster Drum Rocker Arm Roller Bearing System** - Patent 7003897 describes an industry coffee roaster which includes a coffee roaster drum and coffee roaster casing. The casing is fitted with bearings journals to allow the drum to rotate horizontally. The invention also contains notch fittings to keep the drum in place with the casing. This patent is applicable to the design because it represents a way to control the thermal expansion. The patent specifies that industry roasters should use cast iron while designing roasters; however, Roasting Innovation will use stainless steel in its designs.

**Method and Apparatus for Roasting Coffee Beans** - Patent 6036988 presents a small coffee roaster that uses heated air flow and drum rotation to roast coffee. This patent is
applicable to the design because air flow will be the preferred way to heat the coffee beans and also alternative design on a roasting drum.

Fluidized Bed Coffee Roaster – Patent 5394623 describes a self-controlled coffee roaster which monitors the coffee bean temperature. The roaster also injects water into the air stream to quench the coffee beans when the roasting process is complete. This patent is applicable to the design because it offers a different perspective to roasting coffee beans. Fluidized bed systems allow for controlled mixing and heating because these systems insert small amounts of the product instead of heating the entire product all at once.

Coffee Roasting Process and Apparatus – Patent 5287633 presents an industry coffee roaster that includes drum fins, shaft bearings, and a gear motor. This patent is similar to the client’s current product line and is applicable to the design because it allows for insight into advantages and disadvantages of similar designs. This also would provide some insight on how to control the thermal expansion of high end industry coffee roasters.

Dual shaft pan mixer – Patent 4758095 uses dual shafts with attached paddle mixers. The shafts are connected to a worm gear which is then powered by a motor. The paddles also contain shovels which help mix the solids. The rotations of the shafts are opposite directions, while the areas of sweep overlap each other. This patent shows how dual shaft mixers can be used for food processing methods.

Coffee Roaster – Patent 4691447 presents a coffee roasting drum that rotates on a diagonal axis. The roaster uses air flow to heat the coffee beans. This patent is applicable to the
design because a diagonal axis drum allows for easy outlet flow. However, the heating of the drum could be an issue for an industrial sized roaster.

**Industrial Economy**

The growth of coffee consumption around the world has caused an increase in the coffee industry and the demand for coffee by consumers ever since it was first discovered in Ethiopia around 600 AD. One of the main economic conditions that have directly affected the industry is the changing dietary patterns by consumers and the emphasis on living healthier (IBISWorld). Coffee is actually a healthy beverage for consumers and even can help lower the risks of certain kinds of cancer, Type 2 diabetes, Alzheimer’s disease, and heart disease (IBISWorld). This has directly affected consumers within the age group of 18 to 24-years old because they are becoming more health conscious (IBISWorld).

The world price of crude oil is another economic condition that will affect the coffee industry. It impacts the price of transportation, which in turn will affect the profitability of the coffee industry (IBISWorld). This is a very important aspect of the industry because so many of the industry’s inputs are from foreign markets (IBISWorld).

Also, the demand from grocery wholesalers, who form a crucial link to supermarkets, supermarkets and grocery stores play a significant role in the economic conditions. Wholesalers, who account for 73.2% of the market, are essential because they affect which products make it onto the store shelves (IBISWorld). The supermarkets and grocery stores are the direct link between producers and consumers; therefore, coffee producers need to
establish relationships with the supermarkets and grocery stores to gain competitive advantages (IBISWorld).

The actual price of the green coffee bean crops is another important economic condition for the coffee industry. The green coffee beans are the primary input into coffee production (IBISWorld). This in turn also affects the profitability for producers, which has brought to light the unethical treatment of growers in developing countries, which can affect the price of the coffee beans. Sustainable and fair-trade production is a continuing issue within the coffee industry (IBISWorld).

The coffee industry is growing at a consistent rate despite the global recession and by 2009, over 54% of Americans reported to drink at least one cup of coffee per day (IBISWorld). The increase in the industry is expected to record an average annual growth of 1.8% and to reach a total worth of $6.54 billion in the United States by 2010 (IBISWorld). By 2015, the industry is predicted to grow at an average annualized rate of 2.0% while reaching a total worth of $7.22 billion (IBISWorld). Part of the increase in the industry is the increase in consumption for health benefits but also there is a wider range of flavors available, which has stimulated demand.

The supply of coffee beans is the foremost concern for the industry and plays an important part in its current size and ability to grow. Coffee is grown in rich soil, primarily in high altitude, tropical climates near the equator. The main countries which grow coffee beans are Ivory Coast, Puerto Rico, Costa Rica, Mexico, Guatemala, Kenya, Colombia, Yemen, Ethiopia, Brazil, and Indonesia. The primary coffee producer in the United States is Hawaii.
Coffee bean prices can be very unpredictable due to weather conditions that play an important part in the profitability of the coffee industry (IBISWorld). For example, in 2007 production revenue fell 9.9% due to adverse weather conditions (IBISWorld). Ethical consumerism plays an important part in the production of coffee beans. Out of the world’s coffee, 50% is grown by small family growers in developing countries (IBISWorld). Many coffee retailers and consumers today take into account the issue of fair-trade when buying or selling coffee including Dunkin’ Donuts, Starbucks and McDonald’s (IBISWorld).

Over the last five years, the coffee industry has witnessed a 1.6% increase in the number of coffee production establishments annually (IBISWorld). The employment increased at a slower rate of 1.1% over the same period of time (IBISWorld). Also, the consumption of coffee has grown from an average of 24.3 gallons of coffee per person per year in 2005 to 24.7 gallons per person per year in 2009 (IBISWorld). While this may not seem like an extreme increase, it is still enough to play a significant role in the industry. Gourmet and imported coffee have also helped to increase the coffee industry. On average, 17% of the adult population consumed a gourmet beverage, including tea or coffee, on a daily basis (IBISWorld).

Standards

The industry standards for the coffee industry, especially for coffee roasters, can range into a variety of different categories and there are not any major or specific standards that are required for the coffee roasters. Most of the standards refer to the beans and their quality. There are two standard grades, premium and specialty (Specialty Coffee Association of America, SCAA). According to the SCAA, beans should not have any primary defects and a
maximum of five secondary defects, which include parchment, hull or husk, broken or chipped beans, insect damage, partial black or sour, shell, small stones or sticks, or water damage to the beans (SCAA). The beans should have 10-12% moisture content. They should also meet the SCAA’s cup evaluation of eighty points or above, which is based on a sixteen point scale which evaluates eleven different coffee characteristics (SCAA).

The ethical treatment of workers is becoming a growing standard within the industry. It is becoming more and more common for ethical treatment of workers, especially in developing countries, to be a deciding factor in the production or purchasing of coffee. Ethical coffee groups and lobby groups are developing and establishing new standards defining what is considered unethical treatment of workers within the coffee industry (IBISWorld).

Regulations

The government regulations for the coffee industry are still developing because the industry itself is still developing. However, some of the major regulations that could affect US RoasterCorp are air quality regulations. Many of these are done on a state or county level and there are not any on a federal level specifically for coffee roasters. Specifically in Sacramento County, California, there are regulations on air quality and emissions due to coffee roasting. Attached in Appendix B is the listing of all the specific regulations for this part of California that will be a possible restraint for US RoasterCorp.

Also, the environmental impact from the Environmental Protection Agency regulates the food processing side of the industry. Many environmental regulations affect US RoasterCorp including the Clean Water Act, Clean Air Act, Pollution Prevention Act and the
Resource Conservation and Recovery Act (IBISWorld). However, these do apply more to the food processing side of the industry including the grinding as opposed to the roasting. However, the Pollution Prevention Act currently lacks the regulatory power need to encourage companies to implement pollution prevention practices (IBISWorld.)

The regulation of public health and product labeling also affect the coffee industry. The Food and Drug Administration (FDA) is the primary regulator of public health and product labeling. The FDA requires that all of the coffee have the proper labeling that includes the nutrition information and bears nutrient content claims as well as certain health messages available to the consumers (IBISWorld).

**Competitors**

US RoasterCorp has many competitors and some of these competitors have resources that exceed those of US RoasterCorp. One of the major competitors is Primo Roasting. Primo Roasting was founded 26 years ago by Marty Curtis, and specializes in roaster rebuilding and performance enhancement as well as afterburner design and fabrication. Primo Roasting is located in Rose Bud, Arkansas. Primo’s largest roaster is their PRI-265 which holds 310 pounds of green coffee beans. They use the Internet for their primary marketing strategy.

Another competitor that US RoasterCorp faces is Has Garanti. Has Garanti is based out of Turkey, and sells in 15 different countries; America, Canada, England, Australia, New Zealand, South Africa, and Taiwan but most of their products are sent to Europe and African countries. They were founded by Remzi Aydin in 1954. Their largest roaster is the HSR 180 which is
considered one of their industrial roasters and it holds 180 kilograms (396.83 lbs) of green coffee beans. They use word of mouth and the Internet for marketing.

The third competitor is Ambex Roasters, and was founded by Terry Davis. Ambex sells roasters, controls, equipment, maintenance, and also provides training. They are based in Clearwater, Florida, and try to visit many trade shows. Their largest roaster is the Ambex YM-120 and it holds up to 240 pounds maximum. They rely solely on word of mouth and the Internet for their marketing.

Next is Diedrich Manufacturing. Diedrich is out of Idaho and is a family company. The actual company was founded in 1980 but they were around before then. Diedrich attends several industry events; four are on the schedule until September 2011. They rely heavily on the tradeshows for their marketing. They have two series of roasters, the IR and the CR. Of the IR series the largest is the IR-12 that holds 12 kilograms of beans. The CR series, on the other hand, is quite a bit bigger. The largest that they have a picture of on their website is the CR-350 which holds 350 kilograms but they do have drawings for up to the CR-490 which would hold 490 kilograms (1080.27 lbs) of beans.

US RoasterCorp’s last competitor is Probat. They were established in 1868 but their first roaster did not come out until 1920. They are located primarily in Germany but also have companies in Italy, U.S. and Brazil. They advertise that they can process cocoa, nuts, malt, and coffee. Probat publishes a magazine that began in 2006 called LEONARDO, which is their major marketing strategy. They have even started to offer what they are calling environmental friendly exhaust gas treatment. But, even with this treatment their roasters do not pass air
quality regulations in southern California. Probat has three different lines of roasters. First in their Saturn line, the largest they have made so far, is the Saturn 4000 and it holds between 350-550 kilograms of beans. Second is the Neptune line, where their largest is the Neptune 1500 and it is stated to hold between 240-320 kilograms. Lastly is the Jupiter line, the largest is the Jupiter 5000 which holds between 550-750 kilograms of beans.

**Client Characteristics**

Buying practices for US RoasterCorp include purchasing metal from Boyd Metals, AF Co., Jorgensen, and Special Metal. While it is necessary to purchase some materials, US RoasterCorp prefers to and primarily builds all of their equipment in house.

The current market size for US RoasterCorp is $2.5 million each year. However, assuming every job works out flawlessly, the potential market size could be up to $5 million each year. This means that this year they will sell $2.5 million worth of their coffee roasters and rebuilding services. After the finishing of the 300 kilogram roaster they expect their gross sales to expand to $5 million per year, therefore doubling their profit from sales.

US RoasterCorp attends approximately two trade shows a year and has subscriptions to several coffee industry magazines. U.S Roaster Corp obtains many of its product and rebuilding sales by going to trade shows but does not currently advertise in any of the coffee industry magazines. Currently, US RoasterCorp is selling to average sized corporations and small startup companies, as well as to companies that are not directly associated with the coffee industry, such as to Lowe’s corporate office. They plan to begin selling to big-name coffee corporations such as Folgers and Starbucks by building larger, industrial sized coffee roasters such as the 150
kilogram and 300 kilogram coffee roasters. The larger coffee roasters would be more desired by
the larger coffee corporations because they roast large amounts of coffee every day to sell to
their customers and a smaller sized coffee roaster would not be able to keep up with the
demand.

The main customers for the 300 kilogram coffee roaster will be coffee professionals. They desire
gourmet coffee and demand consistency in how their coffee tastes. They are food
service professionals who sell their coffee to loyal customers. The buying firms that would
purchase a 300 kilogram coffee roaster are companies such as Starbucks, Folgers, and some
hotel chains. These companies are picky and need their coffee to taste perfect, or at least
consistent. The owners and employees of the companies who would purchase a 300 kilogram
tend to be more affluent people who demand consistent, high quality taste in their coffee.
These companies often appeal to wealthier people, and sell their coffee as being the best.

The products produced by US RoasterCorp are currently used solely to roast coffee
beans. However, it could also be used to roast nuts, other beans, and almost any other grain
type food. There are many different markets which a 300 kilogram coaster could be a part of,
but US RoasterCorp would prefer to stay solely within the coffee market.

There are online resources such as Coffee Universe at coffeeuniverse.com. On this site,
coffee lovers can learn about coffee and they can also purchase coffee roasters and various
other coffee related machines. There is also market research available in coffee houses and
coffee providers’ stores. Some of the companies that US RoasterCorp could market with would
be Java Daves, Starbucks, Seattle Coffee, Folgers, and some hotel chains. Additional market
research should be done with magazines. Roasting Innovation has already researched a list of potential magazines available for US RoasterCorp to advertise and market in. Some magazines that could be used are Café Magazine, Coffee Explorer, Coffee Geek, and Coffee Review. These magazines are primarily viewed by others within the coffee industry. Many coffee producers, coffee roaster manufacturers, coffee retailers, and coffee consumers all look at these magazines.

**Environmental, Societal and Global Impacts**

Southern California has more strict air pollution emission regulations than any other area of the United States of America. Currently, there are not any roasters sold on the market that are allowed to be operated in southern California because they exceed the more strict air quality regulations. US RoasterCorp plans to be the first company to build an industrial coffee roaster which can legally operate in this area of the United States of America. Comparisons of the Air Quality Standards can be seen in Appendix A.

**Media and Communications**

**Website**

Roasting Innovation will develop a team website to promote the work done on the 300 kilogram roaster as well as the promotional aspects of the marketing plan. Also, this will help with the visibility of the product. This website will be built for the purpose of promoting our team design, but US RoasterCorp may use it in the future on their website. Roasting Innovation
will also include a video of our design from SolidWorks on the website showing the details and specifications of the 300 kilogram roaster.

**Specifications Sheet**

Roasting Innovation will also develop a specifications sheet to be used to give the specifics of the coffee roaster. It will allow US RoasterCorp to adequately discuss the details of the roaster with their customers.

**Brochure**

A promotional brochure will also be developed for the marketing campaign. The brochure will explain the new coffee roaster and the capabilities of the roaster, as well as how it can improve current roasting processes. The brochure will be sent out to customers, along with the specifications sheet. It will also be used at trade shows, conferences and other industry gatherings.

**Pictorial User Manual**

Also, a pictorial user manual on how to use the coffee roaster will be developed for customers of US RoasterCorp. The manual will include pictures of different stages of the roasting process, including pictures of the beans throughout the process as well as differences in roasting times and how that affects the beans.
Business Plan

1. Executive Summary

U.S Roaster Corp has been developing larger roasters to appeal to an increased market. They have encountered a few problems with thermodynamics which is why they have asked Roasting Innovation to help. Roasting Innovation needs to design and produce a drum and drive train for a 300 kilogram roaster that can withstand high temperatures. The 300 kilogram roaster needs to be reliable, easily reproducible, and remain safe to operate.

1.1. Objectives

US RoasterCorp expects that this product will raise approximately 3 million dollars per year for their company.

1.2. Target Customers and Market Analysis

Currently, US RoasterCorp is selling to average and wealthy corporations, not always associated with the coffee industry. They plan to begin selling to big-name coffee corporations. In order to attract the bigger companies into buying their products they are beginning to move away from the smaller roasters on their line, and trying to build bigger roasters which the big name coffee companies would be more interested in buying. The customers for the 300 kilogram coffee roaster will be coffee professionals. They desire gourmet coffee and demand consistency in how their coffee tastes. They are food service professionals who sell their coffee to loyal customers.
1.3. Competitive Products

US RoasterCorp is completely American made unlike most other coffee roaster manufacturers. They also have very quality products for the price customers pay. Their knowledge of the industry and the experience rebuilding other company’s roasters places them above the competition.

Competitors:

1. Primo Roasting- PRI-265 holds 310 lbs of green beans
2. Has Garanti- HSR-180 holds 390 lbs of green beans
3. Ambex- YM-120 holds of 240 lbs of green beans
4. Diedrich Manufacturing- CR-490 holds 1080 lbs of green beans
5. Probat- Jupiter 5000 holds 1650 lbs of green beans

2. Target Customers

US RoasterCorp targets their previous customers for return business. For secondary customers, US RoasterCorp relies on word of mouth and the Internet to refer people to them. Roasting Innovation has compiled a list of US RoasterCorp customers whom were contacted and asked to complete a survey on their preferences, including their current roasters (Table 2).
Table 2: List of customers, their contact information, and survey

<table>
<thead>
<tr>
<th>Customers</th>
<th>Contact Person</th>
<th>Reader Purchased</th>
<th>Contact Number</th>
<th>When Contacted</th>
<th>What do you value most about your current machine?</th>
<th>What is something you wouldn’t change about your machine?</th>
<th>Would you buy another machine from U.S. Roaster Corp? Why?</th>
<th>If you had to change one thing, what would it be?</th>
</tr>
</thead>
<tbody>
<tr>
<td>Broadway Cafe</td>
<td>Jan Gates</td>
<td>Sample Reader</td>
<td>815-679-5897</td>
<td>11/2/2010</td>
<td>Mostly routine with Dr. Death reader ease of maintenance. Likes the ability to read and cool at the same time and likes to read smaller batches than what the machine is.</td>
<td>Yes, if they could be up to the standards of Dr. Death. Temperature readout, wants as many probes as possible.</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Down East Coffee</td>
<td>Terry Montague</td>
<td>12Kilogram Reader</td>
<td>506-575-9222</td>
<td>11/20/2010</td>
<td>Links rise and roasted testing coffee</td>
<td>Energy efficient</td>
<td>Yes, nice people</td>
<td></td>
</tr>
<tr>
<td>First Light Coffee</td>
<td>Wall Manchester</td>
<td>12Kilogram Reader</td>
<td>207-455-1196</td>
<td>11/10/2010</td>
<td>Automation (PID)</td>
<td>Anything</td>
<td>Yes, very good quality and really nice people.</td>
<td></td>
</tr>
<tr>
<td>Forestlake Coffee</td>
<td>David Edwards</td>
<td>5Kilogram Reader</td>
<td>429-977-1873</td>
<td>11/20/2013</td>
<td>Left Message</td>
<td>Energy efficient</td>
<td>Links rise</td>
<td>Yes, good people there</td>
</tr>
<tr>
<td>Mystic Coffee Roasters</td>
<td>Shawn Hippom</td>
<td>5Kilogram Reader</td>
<td>815-425-2044</td>
<td>11/20/2013</td>
<td>They get lots of use out of it.</td>
<td>the fuel usage</td>
<td>Yes, they are nice and engaging.</td>
<td></td>
</tr>
<tr>
<td>Red River Coffee Co.</td>
<td>H. Dobson &amp; H. Pellicer</td>
<td>5Kilogram Reader</td>
<td>540-399-0746</td>
<td>11/20/2010</td>
<td>Lack of really nice, and energy efficient</td>
<td>airflow monitor</td>
<td>Yes, they are easy to deal with, low cost for what you get and American made.</td>
<td></td>
</tr>
<tr>
<td>Roadmasters Coffee</td>
<td>David Fullerton</td>
<td>12Kilogram Reader</td>
<td>506-756-9846</td>
<td>11/20/2010</td>
<td>Bedding up all-electric</td>
<td>environmentally friendly</td>
<td>Yes, they have good services</td>
<td></td>
</tr>
<tr>
<td>Serious Coffee &amp; Tea</td>
<td>Steve Southerland</td>
<td>5Kilogram Reader</td>
<td>416-727-7089</td>
<td>11/20/2013</td>
<td>Don’t use it right now</td>
<td>any change that is for the better</td>
<td>Depending on the future product. If good then yes</td>
<td></td>
</tr>
</tbody>
</table>

3. Target Users

The primary users of this product will be larger coffee houses and roasting factories. The people who will use the machine will monitor the temperature and capacity throughout the roasting process. This product will help smaller coffee houses grow tremendously.
throughout the exponentially larger capacity of the roaster. Being more energy efficient and cost efficient will also help the smaller business grow when they use this product.

4. **Product Description & Positioning Statement**

For the owner of coffee houses who would like to grow their business with a larger roaster, US RoasterCorp with their 300 kilogram coffee roaster is a roasting product that is highly energy efficient, cost efficient, American made, and comes with a company that has a high level of expertise in the rebuilding/manufacturing coffee roasters. Unlike Probat or Deidrich, US RoasterCorp is the only coffee roaster that is able to pass air quality standards in Southern California.

4.1. **Business Problem, Product Concept and History**

US RoasterCorp’s customers value the fact that the roaster is American made and energy efficient, but they have been experiencing a few problems with the mixing of the beans. US RoasterCorp currently uses fins inside of their roasting drums to facilitate mixing but Roasting Innovation feels like these can be vastly improved with a few different designs which were presented to US RoasterCorp. The outcome of this meeting was that US RoasterCorp felt the changes were unnecessary and too different than their current line of roasters. This prompted Roasting Innovation to rethink the designs and come up with a design that stayed consistent with US RoasterCorp’s current roasters but also would benefit the mixing of the coffee beans.
4.2. Key Messages & Main Benefits:

The new roaster design will facilitate greater mixing and a more even roast of the coffee beans. A new method for emptying the beans will also be implemented. The effect of this will be increased precision in timing of the roasting. The emptying or “belly dump” method will allow for all of the beans to exit at one time instead of in short waves or bursts. This aspect is something that no other roaster manufacturing company has implemented. Although this will be new to the market after marketing and sales descriptions this method will be used in increasing numbers throughout the industry.

5. Market Data, Competitive Products, and Analysis

US RoasterCorp has examined the current market and its competitors and feel as though this is the opportune time introduce a larger roaster. Most of their competitors have larger roasters that have been very profitable for each company. US RoasterCorp knows that their new 300 kilogram roaster will be welcomed into the market and increase profits for the company. Roasting Innovation has already analyzed the competitors (Table 3).

5.1. Competitive Strengths, Weaknesses & Response Statements

Primo Roasting

Strength- Low Cost

Weakness- Poor Quality

Has Garanti

Strength- Nice Looking Equipment

Weakness- Based in Turkey so maintenance is difficult
Ambex

Strength- Attractive website and training courses available

Weakness- Small company with not well developed marketing

Deidrich

Strength- Have some very large roasters

Weakness- Does not have any roasters that can pass air quality standards in California

Probat

Strength- Years of experience and brand loyalty

Weakness- Cast iron fronts are very expensive to replace if cracked

Table 3: Competitors and comparisons

<table>
<thead>
<tr>
<th>Companies vs. Criteria</th>
<th>Accessed on and from</th>
<th>Located</th>
<th>Years manufacturing</th>
<th>Largest Roaster</th>
<th>Industry Events per year</th>
<th>Focus</th>
<th>Marketing Strategies</th>
<th>Strengths</th>
<th>Weaknesses</th>
<th>Opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>Prime Roaster</td>
<td>10-6-2010 from</td>
<td>Rose Bud, Arkansas</td>
<td>26</td>
<td>PR-295 holds 310 lbs of green beans</td>
<td>0</td>
<td>Rebuilding and performance enhancement</td>
<td>Internet and word of mouth</td>
<td>Low cost</td>
<td>Poor Quality</td>
<td>Most opportunities are related with rebuilding</td>
</tr>
<tr>
<td>Has Garanti</td>
<td><a href="http://www.hasgaranti.com">www.hasgaranti.com</a></td>
<td>Turkey</td>
<td>54</td>
<td>HSR-180 holds 300 lbs of green beans</td>
<td>6</td>
<td>Coffee grinders, roasters, and afterburners</td>
<td>Attend trade shows, internet, and word of mouth</td>
<td>Nice looking equipment</td>
<td>Foreign company so maintenance is complicated</td>
<td>Europe and countries that are closer</td>
</tr>
<tr>
<td>Ambex</td>
<td>10-6-10 from</td>
<td>Clearwater, Florida</td>
<td>30</td>
<td>YM-120 holds 240 lbs of green beans</td>
<td>3</td>
<td>Smaller roasters and maintenance</td>
<td>Attend trade shows, internet, and word of mouth</td>
<td>Attractive website and training courses available</td>
<td>Small company with not well developed marketing</td>
<td>With marketing they could get more business</td>
</tr>
<tr>
<td>Diedrich Manufacturing</td>
<td>10-6-10 from</td>
<td>Ponderay, Idaho</td>
<td>30</td>
<td>OR-400 holds 1090 lbs of green beans</td>
<td>5</td>
<td>Roasters and also coffee production</td>
<td>Attend trade shows, internet, and word of mouth</td>
<td>Have some very large roasters</td>
<td>Don't have any roasters that can pass air quality standards in CA</td>
<td>Once they catch up with the PLC control system, they can expand</td>
</tr>
<tr>
<td>Probat</td>
<td>10-6-10 from</td>
<td>Hamburg, Germany</td>
<td>100</td>
<td>Jupiter 5000 holds 1850 lbs of green beans</td>
<td>10</td>
<td>Roasters and training courses</td>
<td>Produce own magazine, attend trade shows, internet</td>
<td>Years of experience; brand loyalty</td>
<td>Cast iron fronts are very expensive to replace if cracked</td>
<td>They have already expanded</td>
</tr>
<tr>
<td>U. S. Roaster Corp.</td>
<td>10-8-10 from</td>
<td>Oklahoma City, Oklahoma</td>
<td>6</td>
<td>Revelation 300 holds 660 lbs of green beans</td>
<td>3</td>
<td>Rebuilding and manufacturing</td>
<td>Word of mouth and internet</td>
<td>Quality products and maintenance, knowledge of industry</td>
<td>Not very long manufacturing</td>
<td>Expanding into the larger market. Revelation in South California</td>
</tr>
</tbody>
</table>
Design Requirements

- Hold 300 kilograms worth of coffee beans
- Allow for a 30% volume clearance of open space in the drum after the coffee beans have been roasted
- Improve the exiting of the coffee beans from the roaster to the cooler
- Account for thermal expansion
- Maintain mixing standards so as to reduce over-, under-, and uneven roasting
- Needs to meet air quality standards in Southern California, the highest in the United States of America

Calculations and Testing

Calculations

Volume

Determining the volume, diameter, and length of the 300 kilogram drum are the first calculations that need to be completed in order to come up with a basic drum design. The drum’s volume was calculated using Equation 1. Using the 150 kilogram drum already developed by U.S. Roaster, a rough estimate of the overall drum volume was determined. The diameter and length of the drum were then calculated using the volume. Equation 2 is to calculate the volume of the dual paddle fluidized mixer.
$$= 4\pi \ 2\pi \quad (Equation \ 1)$$

Where: $V =$ volume of the drum ($feet^3$)

$$D =$ diameter of the drum (feet)

$$L =$ length of the drum (feet)

Table 4. Diameter and length calculations based on the volume of the drum

<table>
<thead>
<tr>
<th>Diameter (feet)</th>
<th>Length (feet)</th>
<th>Diameter:Length</th>
<th>Volume (feet$^3$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4</td>
<td>5</td>
<td>1.250</td>
<td>62.8</td>
</tr>
<tr>
<td>4</td>
<td>4.5</td>
<td>1.125</td>
<td>56.52</td>
</tr>
</tbody>
</table>

$$= \pi \ 2r + \pi + 12\pi h + r \quad (Equation \ 2)$$

Where: $V =$ volume of the drum ($feet^3$)

$$r =$ radius of the swing doors (inches)

$$s =$ side length of the drum (inches)

$$s_T =$ side length of the top (inches)

$$d =$ internal distance (from side to side) of drum (inches)

$$L =$ length of the drum (feet)
Table 5. Volume Calculations of the Dual Paddle Design

<table>
<thead>
<tr>
<th>Drum Volume Calculations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Side Length (in)</td>
</tr>
<tr>
<td>19.5</td>
</tr>
<tr>
<td>20</td>
</tr>
</tbody>
</table>

The diameter: length ratio also needs to be considered. The design specifications require the length of the drum to be no greater than 25% of the diameter. Therefore, based on the calculations and specifications the proposed diameter and length of the drum is 4 feet and 4.5 feet, respectively. These results can be seen in Table 4. The dimension calculations for the dual paddle fluidized mixer can be seen in Table 5.

Thermal Expansion

Changes in temperature cause metal to contract and expand. The amount of expansion due to temperature increases is dependent upon what type of metal is subjected to the heat. When a metal such as stainless steel is heated it can expand considerably, while cast iron expands a relatively small amount. This can become a serious design issue with coffee roasters because they can reach temperatures up to 1000°F. Special design requirements must be met in order to build a large, industrial coffee roaster which can function properly at these temperatures. In order to take in account the thermal expansion in the coffee roaster design, the amount of expansion must first be calculated. The thermal expansion can be done using Equation 3.
\[ \Delta = * \times (\ - \ ) \]  

*(Equation 3)*

Where: \( \Delta L \) = the change in length due to thermal expansion (inches)

\[ c = \text{coefficient of thermal expansion (}^{\circ}\text{Fahrenheit)} \]

\( L_i = \text{initial length of the drum before the temperature change (inches)} \)

\( T_f = \text{the final temperature (}^{\circ}\text{Fahrenheit)} \)

\( T_i = \text{the initial temperature (}^{\circ}\text{Fahrenheit)} \)

Using Equation 3, the results for the amount of thermal expansion that is calculated when heating chromium stainless steel, alloy steel, stainless steel, and carbon steel up to 1000\(^{\circ}\)F can be seen in Table 6.

**Table 6. Change in length calculations based on the thermal expansion of different materials.**

<table>
<thead>
<tr>
<th>Material</th>
<th>Length(_i) (in)</th>
<th>Temperature(_i) ((^{\circ})F)</th>
<th>Temperature(_f) ((^{\circ})F)</th>
<th>Coeff. of Thermal Expansion ((^{\circ})F)*</th>
<th>Change in Length (in)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cr Stainless Steel</td>
<td>54</td>
<td>70</td>
<td>1100</td>
<td>0.00000663</td>
<td>0.382</td>
</tr>
<tr>
<td>Alloy Steel</td>
<td>54</td>
<td>70</td>
<td>1100</td>
<td>0.00000722</td>
<td>0.416</td>
</tr>
<tr>
<td>Stainless Steel</td>
<td>54</td>
<td>70</td>
<td>1100</td>
<td>0.0000103</td>
<td>0.594</td>
</tr>
<tr>
<td>Carbon Steel</td>
<td>54</td>
<td>70</td>
<td>1100</td>
<td>0.00000797</td>
<td>0.460</td>
</tr>
</tbody>
</table>

*Coefficients were obtained from Hose Master, LLC at [http://www.hosemaster.com/products/technical/thermalexpansion.php](http://www.hosemaster.com/products/technical/thermalexpansion.php).
Based on the information in Table 6, the material which provides the least amount of thermal expansion is the chromium stainless steel. The material which has the largest amount of expansion due to temperature change is stainless steel. A cost analysis must be done in order to determine whether the cost addition of reducing thermal expansion is necessary.

**Tests to be Conducted**

*Test #1 Mixing*

We will test the mixing of the beans once we develop a new fin design. We will paint the beans several different colors according to where they are placed in the drum. We then will rotate the drum to see if the beans mix well with the new fin design. Mixing is important to prevent under or over cooking and uneven cooking of the beans.

*Test #2 Uniform Heating*

We will test the uniformity of the heating of the coffee beans. Uniform heating is necessary for quality roasting in order to avoid uneven bean roasting. It also helps prevent under roasting and over roasting. We will test the heating by placing thermocouples around the drum and test to see how much the temperature varies.

*Test #3 Pressure*

We would like to increase the pressure inside the drum slightly in order to improve the overall efficiency of the roasting. This may be done by the addition of low levels of Nitrogen into the drum. Nitrogen would be used to create a more anaerobic environment for reasons discussed in *Test #8 Anaerobic*. 
Test #4 Airflow

In order to have even roasting the airflow within the drum should be steady and uniform. This will help reduce hot spots and keep the roasting of the coffee beans even.

Alternative Design Concepts

Design 1: Hook Rotating Drum

In this proposal, the typical fin design would be replaced with horizontal hooks which would be welded along the entire length of the drum. These hooks would pick up the beans and then throw them in the air during each rotation. This would create a semi-fluidized motion for the coffee beans and encourage even roasting of the coffee beans. On the back end of the drum would be a screen. When the roasting is completed the screen could be moved along the entire length of the drum, pushing all of the roasted coffee beans through the outlet of the drum. This allows for quick evacuation of the coffee bean, again allowing for a more even roasting.
Figure 1: Drum

Figure 2: Drum with Hooks and Axel
Design 2: Single Paddle Mixer

This design features the traditional roasting drum shape but it differs in mixing method it uses. This proposal uses a single rotating paddle to keep the beans mixing and roasting evenly. The paddle design will also be more efficient than the traditional rotating drum designs. It will accomplish this by requiring a smaller power source to rotate the paddles. This design will also feature a door at the bottom of the fixed drum. This allows for a faster exit for the coffee which interns permit a more even roast of the beans. The barrel would be heated one of two ways. The first possibility is to keep the current heating system in place. The second option consists of feeding the hot air into holes cut into the bottom or top of the drum. Either of these would be valuable options.
Figure 4: Drum

Figure 5: Drum with Paddles
**Design3: Dual Paddle Fluidized Mixer**

In order to offer optimal roasted coffee, the coffee must be evenly roasted through fluidized mixing. However, the traditional design of an industry coffee roaster could be changed slightly in order to accommodate for thermal expansion. Traditional roasters use coffee ovens or drums that rotate on a horizontal axis. The dual paddle fluidized mixer is designed to more efficiently mix the coffee beans while maintaining a similar aesthetic look to traditional roasters. The design no longer encompasses a roasting drum, but instead relies on two shafts with sweep paddles. The shafts are powered by gear sets and motors. The sweep paddles will be offset on the two shafts to efficiently move the coffee beans. The roaster will be heated through air flow coming from four nozzles that are placed at the top of the roaster. The coffee
beans enter from the inlet situated on top of the roaster. The coffee beans will then land on the sweep paddles. The sweep paddles will turn in opposite directions at 35 rpms. After the coffee beans are roasted, the roaster doors will swing open and allow the coffee beans to fall onto the cooler. This roaster will also contain a front face plate to allow for maintenance applications.

**Figure 7: Frame of Dual Paddle Mixer**
Figure 8: Frame with Paddles

Figure 9: Assembly of Dual Paddle Mixer
## Financial Analysis

### Table 7: Testing and Miscellaneous Requirements

<table>
<thead>
<tr>
<th>Product</th>
<th>Amount</th>
<th>Price per Unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sprockets (#35, #40)</td>
<td>1</td>
<td>$200</td>
<td>$200</td>
</tr>
<tr>
<td>Plastic sheeting for Testing</td>
<td>1 .25x12x24</td>
<td>$65</td>
<td>$65</td>
</tr>
<tr>
<td>Metal sheeting for Testing</td>
<td>2 .008x4x10</td>
<td>$15</td>
<td>$30</td>
</tr>
<tr>
<td>Fittings/bolts</td>
<td>--</td>
<td>--</td>
<td>$10</td>
</tr>
<tr>
<td>5 gallon plastic bucket</td>
<td>1</td>
<td>$15</td>
<td>$15</td>
</tr>
<tr>
<td>Thermocouples</td>
<td>3</td>
<td>$30</td>
<td>$90</td>
</tr>
<tr>
<td>Gear Motor</td>
<td>1</td>
<td>$300</td>
<td>$300</td>
</tr>
<tr>
<td>Pressure Gage</td>
<td>1</td>
<td>$15</td>
<td>$15</td>
</tr>
<tr>
<td>Dye/Paint</td>
<td>4 colors</td>
<td>$5</td>
<td>$20</td>
</tr>
<tr>
<td>Drive shaft</td>
<td>1</td>
<td>$10</td>
<td>$10</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>$755.00</strong></td>
</tr>
</tbody>
</table>
Table 8: Design 1 Hook Rotating Drum

<table>
<thead>
<tr>
<th>Product</th>
<th>Amount</th>
<th>Price per Unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless Steel Drum</td>
<td>1</td>
<td>1.635 ($/lb.)</td>
<td>$981</td>
</tr>
<tr>
<td>12.5 x 4.5 feet (600lbs)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Welding</td>
<td>1</td>
<td>$49</td>
<td>$49</td>
</tr>
<tr>
<td>Shaft</td>
<td>1</td>
<td>$720.90</td>
<td>$720.90</td>
</tr>
<tr>
<td>Hooks (28lb)</td>
<td>4</td>
<td>$1.635 ($/lb)</td>
<td>$183.12</td>
</tr>
<tr>
<td>Bearings</td>
<td>1</td>
<td>$89.80</td>
<td>$89.80</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>$2023.82</td>
</tr>
</tbody>
</table>
### Table 9: Design 2 Single Paddle Mixer

<table>
<thead>
<tr>
<th>Product</th>
<th>Amount</th>
<th>Price per Unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless Steel Drum</td>
<td>1</td>
<td>1.635 ($/lb.)</td>
<td>$981</td>
</tr>
<tr>
<td>12.5 x 4.5 feet (600lbs)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Welding</td>
<td>1</td>
<td>$49</td>
<td>$49</td>
</tr>
<tr>
<td>Hinges</td>
<td>4</td>
<td>$18</td>
<td>$72</td>
</tr>
<tr>
<td>Paddles (18 lb)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Shaft</td>
<td>1</td>
<td>$720.90</td>
<td>$720.90</td>
</tr>
<tr>
<td>Bearings</td>
<td>1</td>
<td>$48.75</td>
<td>$48.75</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td></td>
<td>$1871.65</td>
</tr>
</tbody>
</table>
### Table 10: Design 3 Dual Paddle Mixer

<table>
<thead>
<tr>
<th>Product</th>
<th>Amount</th>
<th>Price per Unit</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Stainless Steel Drum</td>
<td>1</td>
<td>1.635 ($/lb.)</td>
<td>$981</td>
</tr>
<tr>
<td>12.5 x 4.5 feet (600lbs)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Welding</td>
<td>1</td>
<td>$49</td>
<td>$49</td>
</tr>
<tr>
<td>Hinges</td>
<td>4</td>
<td>$18</td>
<td>$72</td>
</tr>
<tr>
<td>Shafts</td>
<td>2</td>
<td>$720.90</td>
<td>$1441.80</td>
</tr>
<tr>
<td>Paddles (36 lb)</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
<tr>
<td>Bearings</td>
<td>2</td>
<td>$48.75</td>
<td>$97.50</td>
</tr>
<tr>
<td><strong>Total</strong></td>
<td></td>
<td></td>
<td><strong>$2641.30</strong></td>
</tr>
</tbody>
</table>

### Table 11: Total Cost of Each Design

<table>
<thead>
<tr>
<th>Design</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Testing, Miscellaneous, and Design 1 Hook Rotating Drum</td>
<td>$2778.82</td>
</tr>
<tr>
<td>Testing, Miscellaneous, and Design 2 Single Paddle Mixer</td>
<td>$2626.65</td>
</tr>
<tr>
<td>Testing, Miscellaneous, and Design 3 Dual Paddle Mixer</td>
<td>$3396.30</td>
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Works Cited


   <http://www.hasgaranti.com.tr/>


Appendix A – Scientific Literature
Appendix B – Patents