Handheld Electronic Vapourizer for Sedating Bees

BREE 495 Engineering Design 3

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Abstract

Can modern technology improve upon traditional bee smoking designs? Our team set out to answer this question. We set out by conducting a literature review and interviewing our clients to find what are the inherent faults of traditional bee smoking practices. This was followed with an external search of relevant designs, patents, standards, constraints and business opportunities to guide the design process. After settling on a vapourizer based design, we conducted feasibility and effectiveness calculations which confirmed that our prototype would have sufficient heat transfer, power and flow. The design details and material costs of our system and subsystem levels are outlined in adequate detail for future researcher replication. This is followed by a validation of our design when compared to the target specifications and criteria, which gave positive results in all categories except for safety. We believe that further input is required to increase the safety level of this design to sufficient levels. Lastly, we considered the social, economic and environmental impacts of our design including a Life Cycle Analysis to determine the total CO2 emissions (3.48 kg of CO2) over the lifetime of this product. Research recommendations for further research are offered in the conclusion to bring this design to a market ready product.

1. Introduction

Bees are an integral part of a functional ecosystem, providing benefit to the organisms around. They are nature's greatest pollinators, visiting hundreds, if not thousands of flowers each day. Why are bees so great at pollinating? This is because their bodies are covered in hair, holding pollen that is transferred from flower to flower. Bees are also producers, as honey and beeswax can be found within their hives. Bee hives are the center of a bee colony, containing the queen bee, worker bees and bee larvae. A beekeeper who wishes to open a hive and harvest honey will face a swarm of angry bees, but luckily there are tools which can diffuse the situation. Bee Smokers are a quintessential tool to apiculture and have been used by apiarists throughout history. Smoker technology has not advanced in recent years, utilizing a simple canisters with a live fire inside and an air emission device to push the smoke outwards and into the hives. Our goal is to bring this design into the 21st century by to increasing safety, ergonomics and usability. With help of our mentor and client Dr. Mark Lefsrud, criteria have been outlined with which our team can work to narrow our design options. Our team’s design utilizes electronic vapourizer technology to replace what is currently used in a traditional bee smoker. This report documents the design process, final design and it’s social, economic and environmental considerations. The aim of our design is to provide apiarys with a device that is able to quickly and effectively calm the bees, especially in emergency situations.

1.1 Vision Statement

To design a user-friendly, ergonomic and safe bee smoking device using the latest technology to quickly and effectively sedate bees.

1.2 Literature Review

1.1.1. Traditional Bee Smoking Practices

Beekeeping is a recreational hobby and an agricultural necessity. Many people keep bees for their own pleasure, but bees also have a hand in producing one third of the food on our table. Without the help of bees, pollination would become an extremely laborious task, requiring thousands of man hours yearly. In addition to pollination, bees also produce honey, which is harvested from the combs in their hives. This task requires a beekeeper to become up close and personal with the hives, prying apart the trays to access the sweet commodity within. One challenge to this task is avoiding bee stings, as alarmed bees will defend themselves and their hive to the death.

Beekeepers find it necessary to employ a gambit of self defense mechanisms, including overalls, bee veils, and bee gloves. With a physical barrier between beekeepers and bees, the possibility of being stung decreases. Another self defense tactic is to “smoke” the bees when approaching them (Sethi, 1994). Smoking bees is the process of emitting smoke around and into the hives, which has been observed to calm the bees.

Why does smoke calm bees? To understand this, a basic understanding of bee communication is required. Bees primary method of communication is through release of pheromones. Pheromones can communicate information such as whether or not the queen bee is healthy, can identify hive mates, or guide bees for foraging (Vreeland and Sammataro, 2017). Knowing that smoke will calm bees, Visscher P. et al. wanted to test whether alarm pheromone perception in honey bees is decreased by smoke. This team identified two known alarm pheromones, isopentyl acetate (IPA) and 2-heptanone, and tested to determine how smoke changed a bees perception of these pheromones. Unsurprisingly, the results were that there is a strong negative effect of smoke on honey bees recognition of alarm pheromones, but this affect is only temporary, returning to normal after 15 minutes. Their judgement was that smoke interferes generally with olfaction, and this may be because either compounds in smoke compete for binding receptor sites on the antennal chemoreceptors or are toxic to the nerve cells. Therefore, smoke decreases bees ability to smell an intruder or detect airborne alarm pheromones.

Another result of exposing bees to smoke is that they engorge themselves on honey. It is hypothesized that this reaction is instinctual, as the presence of smoke indicates there is a forest fire nearby, and gorging the honey is a method for preserving the resources of the colony. Some apiarists believe the bees become lethargic from overconsumption (Dudley et al., 2016) and less prone to stinging, but Visscher P. et al. (1995) debunk this claim, saying there are other triggers for engorgement that do not result in a decrease in defensive behaviour.

Smoking bees has been practiced for thousands of years, thought to be one of the earliest discoveries of man, but through the centuries, the base smoker design has not changed greatly. Curtis Gentry gives an overview of the traditional smoker design and steps to igniting it in his paper titled *Small Scale Beekeeping,* written for the Peace Corps.

Functional specifications of a traditional smoker include a firebox with a grate to hold the smoldering material, a nozzle to direct the smoke, hand bellows to increase smouldering, and adequate fuel capacity to not require frequent refueling. It is essential that the smoker remain lit through the entire process and burns slowly giving off cool white smoke. To meet this standard, the design must ensure an adequate air to fuel ratio. Given too much air, the fuel will burn rapidly and may result in excessive flames. Without enough air, the fuel will burn slowly and may go out. An additional consideration is the hand bellow for supplying bursts of air; it must be easy to pump so the users hand doesn't tire quickly.

To successfully smoke bees, a beekeeper must choose their fuel wisely; common choices include, wood shavings, old burlap sacks, dry cow dung or coconut husks. These fuels will burn slowly and give off lots of smoke. Poor choices for fuel include petroleum based substances, sawdust, wood and charcoal because they will either give off black smoke, too much smoke or emit embers which can burn bees and contaminate honey.

The process of lighting a smoker is outlined by Curtis Gentry, which gives an idea for those who have never witnessed the process before. The steps are as follows:

Steps to lighting a smoker

1. Light a piece of paper and place it inside of the smoker
2. Pump the hand bellows until the paper is flaming
3. Once burning, slowly add more fuel (not too much fuel or it will go out) and continue pumping the bellows to keep the fire lit
4. Once the smoker is lit, add some green grass or leaves to the top to catch any airborne embers and to cool the smoke
5. Close the smoker top
6. Periodically pump the bellows so the smoker remains lit

Curtis Gentry notes that the smoke canister will continue to heat up, and may pose a burning hazard if contact with skin is made. It is important to occasionally pump the bellows while working or the user will have to restart the lighting process again. A last point of caution from Curtis Gentry is to dispose of embers within the apparatus when finished, to avoid excess heat damaging the smoker. Additionally, dispose of embers responsibly to avoid starting a forest fire.

1.1.2. Current Handheld Smoke Emitting Devices

Modern smoke emitting devices, or vapourizers, are devices that heat a liquid mixture to produce vapour. Vapourizers different from other forms of combustion as they do not fully combust the contents but instead vapourize it, as the name implies.

Vapourizers are mainly used as “Electronic cigarettes”; they vapourize a liquid that contains nicotine to produce vapour which the user inhales. These electronic cigarettes simulate the sensation of smoking whilst removing the negative aspects of ordinary cigarettes. The vapour that electronic cigarettes produce does not contain the toxic chemicals that are found in tobacco smoke, because the combustion of material changes its chemical composition while vapourizing it will only change its state of matter. The liquid commonly used in e-cigs are either propylene glycol and vegetable glycerin (Dunsworth, 2017). The vapour from these liquids do not contain the multiple carcinogens that traditional cigarette smoke does (Britton et al, 2014).

The e-cigarette industry is at the forefront of the vapourizer industry; they have the greatest need to develop a replacement for traditional cigarettes while still providing the nicotine that its consumers desire. The first generation of e-cigarettes were small and resembled a traditional cigarette in order to appeal to smokers. These devices were low capacity and were generally single use only and delivered a small amount of nicotine, just enough to satisfy any craving (Farsalinos, 2015). Later generations increased in complexity and as a result could deliver more nicotine, had a greater capacity and were overall more powerful devices. As the technology progressed, atomizers became more customizable; users have the ability to replace its coils, wicks and storage tank. This type of atomizer is appropriately called a “Rebuildable Atomizer”. These types of atomizers are capable at running “Sub-ohm” resistances (Farsalinos, 2015), meaning running the coils at a resistance below 1 ohm. Rebuildable atomizers is where the current technology has plateaued, as they are versatile enough to fill a variety of applications. Current cigarette vapourizers are made of a rebuildable atomizer and an electrical “mod”, which is includes the battery, logic board, and user interface. The majority of these vapourizers are constructed from pyrex glass and stainless steel, employing very little plastic (Farsalinos, 2015).

The patent filled by Paul Younger shows a preliminary design of a vapourizer based system. The use of a vapourizer makes this design more advanced than a traditional smoker, but still uses combustion as its power source. Younger’s design uses simple components to construct the smoker; the vapourizer is essentially a propane gas burner. Younger’s design uses a gas camping stove underneath of coiled metal tubing (Younger, 2002). The fuel for the gas burner is stored in a separate plastic container and is fed with a tube. The vapour fluid is stored in another separate container, connected to the metal vapourization coils via tubes. A pump is used to move the vapour fluid from the storage container to pass it through the metal coils and exhaust it out of the nozzle. The size of the device is rather large, similar to a briefcase. The author mentions that his mixture of gassing fluid will not be strictly propylene glycol or glycerin, as he believes it will not be enough to sedate the bees. Instead he suggests using a mixture of the aforementioned chemicals in conjunction with “liquid smoke” at a mixture rate of 18% liquid smoke to 82% propylene glycol or glycerin. Younger (2002) also notes that to achieve vapour that will dissipate more quickly it is best to add in water to the mixture, the higher the concentration of water the quicker the vapour will dissipate.

The liquid smoke referenced above is water soluble food flavouring additive, commonly found in most BBQ sauces. The most common way to create liquid smoke is by pyrolyzing hardwood, however there is not set definition to the correct way to create this product (Montazeri et al., 2012).

1.1.3. Vapourizer Construction and Materials

The construction of vapourizers consist of a battery, heating resistance coil with wicks, microprocessor, tank and e-liquid to fill the tank. There are a number of other parts that increase the usability of e cigarettes but they cannot function without the aforementioned parts. The heating element in a vapourizer is called an Atomizer which comprises a small vapourizer and a wick to draw in some of the e-liquid from the reservoir (Farsalinos, 2015). There are various atomizer designs, each serve their own respective purposes, some atomizers can fit into small, discreet vapourizers while larger devices can reach higher temperatures and provide greater vapour production. Some atomizer designs include Cartomizers and Clearomizers (Farsalinos, 2015). The cartomizer integrates the heating coil into the liquid tank. This saves on space and allows for a more compact e-cigarette, but as a trade off it cannot store as much liquid and limits the number and size of coils. The clearomizer improves on the previous design as it places the atomizer and tank inside a clear glass component so the liquid levels may be seen.

A more advanced and modular vapourizer design is the Rebuildable Atomizer (RBA). There are two subcategories of RBAs; Rebuildable Tank Atomizers (RTA) and Rebuildable Dripping Atomizers (RDA) (Mann, 2018). An RBA allows the user to choose their coil and wicking material, and build the coils themselves (Mann, 2018). The main difference between an RDA and RTA, is the process in which the liquid is fed to the coils. In an RDA the liquid is dripped on to the coils and then vapourized; most RDA's have a small cache of 1 mL for the liquid. For an RTA the liquid is contained in a tank where gravitational and wicking forces feed the liquid onto the coils, replacing the manual dripping method found in an RDA. RTA atomizers can hold a greater volume of e-liquid than an RDA.

Coils types can be assorted by type of metal, gauge or thickness, and the number of wraps. There are five main metals used in the construction of vapes coils ; Kanthal (FeCrAl), NiChrome (Ni80). Stainless Steel, Nickel (Ni200) and Titanium (Ti) (Bickford, 2017). Each metal has respective pros and cons and serves a unique purpose. Metals like Kanthal, Stainless Steel and NiChrome are relatively inexpensive and can be easily sourced, but their downside is that they are harder to work with and contain metals that can be harmful for human health (Bickford, 2017). Temperature control and wattage control are the two ways in which vapourizer can be operated; wattage control simply regulates the wattage sent to the atomizer whereas temperature control regulates the temperature at which the coils run. Of the metals mentioned above only Nickel, Titanium and Stainless Steel can be used in temperature controlled vapourizer while Kanthal, NiChrome and Stainless Steel can be used for wattage controlled vapourizers. As shown, Stainless Steel is the only metal that is versatile enough to be used for both modes of operation (Bickford, 2017). Wire gauge thickness affects the amount of vapour production. Gauges typically start at 32 and go all the way to 22. The higher the gauge the higher the resistance and lower gauge translates into lower resistance and slower ramp up time. For reference, the higher the gauge number the thinner the wire is in diameter, so a 32 gauge wire will be thinner than a 22. Ramp up time is the time in which it takes the coil to reach the correct temperature. Wicking material is also important for atomizer construction. Wicking materials include organic cotton, Japanese cotton pads, Ekowool, silica and Rayon fiber. Organic cotton is the most widely used wicking material due to its properties and availability.

2.0 Customer Needs

2.1 Results From Initial Interview

Our initial conversations with our client Dr. Mark Lefsrud yielded the following table of customer needs. It roughly outlines the topics discussed to give loose criteria for the bee sedation design.

Table 1. Initial Customer Needs List Obtained from Interviews

Ergonomic
Light-weight
Easy to use
Durable
Quick start up
Long lasting battery life
Universal charging
Water/weather proof
User Safety
Harmless for bees
Cannot contaminate honey

Working from from Table 1, our team narrowed the criteria down to three key parameters which encompass the expectations for the final product. These three parameters are ergonomics, usability and safety, which have been described in detail below.

2.2 Criteria Selection

Ergonomics

As specified by the client, the device must be easy to use and ergonomic. Therefore, the design should be be be able to fit in the palm of the average human hand, while containing all necessary components. Beekeepers keep their smoker on-hand through the course of the work-day, therefore the weight needs to be kept low to avoid unnecessary fatigue. If beekeepers are to carry the bee vapourizer all day, a belt holster may be necessary or at the very least it has to fit within a jacket pocket.

Durability is a key parameter, beekeeping is not a delicate career and there is a high probability the smoker can be dropped from waist height. Structural integrity of the device and it's internal components should withstand typical wear and tear.

Usability

The time required to load and ignite a traditional bee smoker is around 2-5 minutes depending on conditions and user experience. An innovative smoker design should start more quickly than a traditional smoker. When using current smoking methods, a full smoker is able to last the entire day, to compete with this, a new design should also last an entire work day. Furthermore, the number of "puffs" emitted to sedate the bees should be equal or less than a traditional smoker device. The charging inputs should be be standardized or universal, allowing the user to interchange the charging cable if it were to break or get lost. Weather conditions when smoking can vary depending on location and the time of year, and emergency situations must be considered as well. The average temperature for a beekeeping season is around 25C (World Weather, 2018) with decreased off season temperatures; a new smoker design must be able to operate in all conditions. For the device to be capable to work season round, it must satisfy these constraints.

User Safety

An innovative bee sedation device must first and foremost be safe. This means that all precautions have been taken to mitigate risks for the user. An area of safety concern is the power source for the sedation device, be it battery, fire or gas powered, a smoker must not explode or ignite. The smoker must adhere to conventional electronic safety protocols and must not pose any inherent risk to the operator.

Bee Safety

Safety consideration pertains to not only the user, but to the honeybees as well. In this regard, the mechanism of bee sedation must not pose any short or long term health threats to the bees. Additionally, the smoke or vapour emitted must not contaminate the honey, as the final product must be safe for bee and human consumption. Standard beekeeping protocols and precautions shall be followed and implemented for this sedation device.

3.0 Target Specifications

Current beesmokers are outdated and rely on adequate technology to perform a task that can be improved and rendered more efficient. Bee smokers use biomass to fuel a fire to create the smoke needed to sedate honey bees. While this is effective, the initiation process is lengthy and often times difficult to complete in less than ideal situations. For example, the fire dies out when there is not enough air flow provided by the bellow, or the biomass itself is damp and does not hold burn properly. Additionally, the smoke produced by this reaction contains CO_2 and other pollutants that are harmful for human health as well as the health of a bee colony. The client wants a more advanced and efficient process instead of relying on techniques from decades passed. This process can be improved by replacing the biomass component with modern technology to reduce the set up time, the amount of pollutants released by the device, and improve the ease of use.

Target specifications for this problem are as follows :

A. Achieving a start up time less than 5 seconds, ideally nearing the point of instantaneous start up. This can be made possible by the use of electronic components powered by batteries that don't require a warm up time before they are ready to be used.
B. An ergonomic handheld shape measured by the surface area and volume of the contact area measuring less than that of the average palm.
C. Easy to use measured by the number of inputs and required maintenance. The goal is to minimize maintenance time
D. Safety of the user and bees made possible by the device producing harmless emissions.
E. Adequate sedation of the bees by emitting a sufficient volume of smoke, measurable by the duration of emissions necessary to render the bees sedated.

The target specifications were periodically checked with the client before and throughout the design and construction process to ensure that the progress being made was up to par with the targets outlined. When design changes were made during the iterative process, a simple follow up was done with the client to gain approval before further work was done.

4.0 External Search

A comprehensive external search was completed to understand the current bee smoking technologies are available to beekeepers. As a part of this search, a commercial benchmark was established, which provided a functional standard for comparison to our design. Additionally, patents were reviewed to better understand the technology which contributes to bee smokers. Following the section on applicable patents is the applicable standards section which looks over which guides and standards should our design comply with. The last two sections, applicable constraints and business opportunity provide a framework for our bee smoker, which our design must fall within to be functionally and economically successful.

4.1 Benchmarking

The benchmarking process is necessary to compare all commercially available products which fill the same market niche as our intended design. An online search reveals that the top commercially available bee smokers are all steel canister designs, relying on combustion and smoke emission through use of hand pumps. There are other patents for bee smokers, and a kickstarter for a vapourizer based design called Apisolis, but none of these are available for purchase as of this report. Therefore, the typical benchmark bee smoker design is outlined below, which essentially encompasses all currently available bee smokers. Included below is a picture of a Mann Lake HD540 Stainless Steel Smoker which is regarded as the number one bee smoker by Beekeepclub.com. This website totes themselves as “the ultimate resource guide for beginners to learn about the charming activity of beekeeping” and offers reviews and guides concerning beekeeping equipment.

Table 2. The Bee Smoker Benchmark

Feature	Bee Smoker Benchmark Design
Size	13 x 11 x 5 inches
Weight	1.81 lbs
Cost	$89.40 CAD
Material	Stainless Steel
Fuel	Organic material (twigs, grass, paper, cardboard, pine needles, kindling, pine cones)
Data retrieved from:	https://www.amazon.com/Mann-Lake-HD540-Stainless-10-Inch/dp/B00B8L5XOS/ref=as_li_ss_tl?ie=UTF8&linkCode=ll1&tag=bekecl-20&linkId=263ea6fc3dd3911a1acb86cbe2a1729f

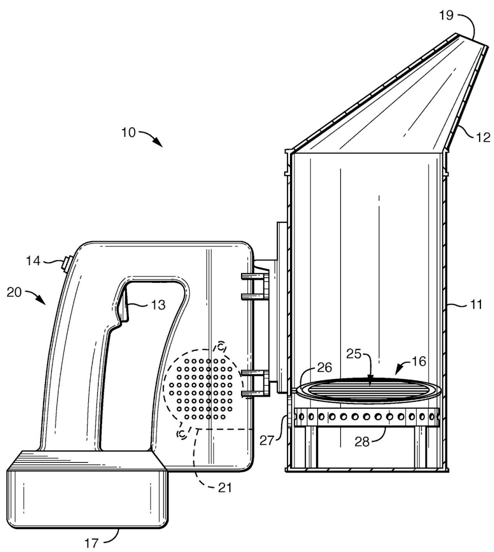
Figure 1. Mann Lake HD540 Stainless Steel Smoker

4.2 Applicable Patents and Alternative Designs

The US8353126B2 bee smoker patent is outlined below, which we considered relevant to bee smokers and their design. Additionally, some information was included regarding Apisolis, which markets itself as a natural bee smoker alternative to traditional smokers.

Bee Smoker Patent US8353126B2

This patent was filed in 2009 by Daniel Stearns, for an “improved bee smoker” which builds upon the principles of the benchmark bee smoker through some simple technological additions. Just as classical smokers, this design (pictured below) utilizes smoke for bee sedation. The two major differences to the benchmark design is that Stearns design uses a resistive heat element to to generate the smoke and a battery powered air flow mechanism to direct the smoke towards the bees. Described in the patent filing, this design has a battery bank in the handle of the smoker, which supplies power when the user activates a switch, turning on the fan and the resistive heater to generate smoke “on demand”. This eliminates the process of starting a fire, and keeping a fire smouldering for the duration of the bee working session. We wish to implement the concept of “on demand smoke” for our own design, as this reduces the safety hazard of keeping a fire lit for the entirety if the bee work session.



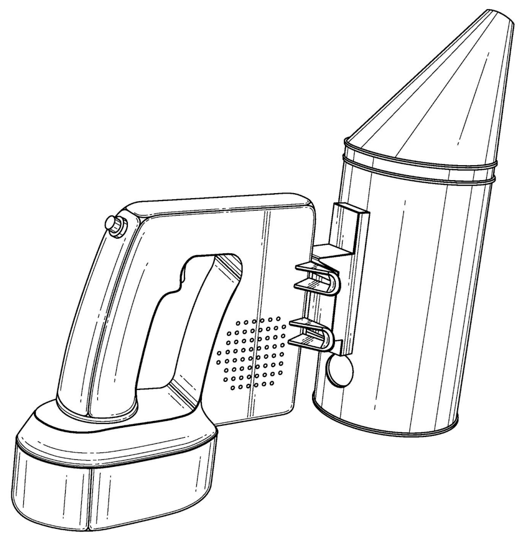


Figure 2.1 and 2.2. Design sketches for patent US8353126B2, the improved bee smoker design.

Apisolis Naturally Active

This product can be found on Indiegogo, a popular crowdfunding website where products, which haven’t reached the marketplace yet, can receive funding from the public (Albresby, 2017). Though Apisolis have not released their patents for our formal review, this product deserves our attention because this is the most progressive bee smoker design. The Apisolis Naturally Active product is a handheld electronic bee smoking design, which emits vapour for bee sedation. This design (pictured below) is an innovative take on classical bee smokers, as it still utilizes a hand bellow to emit the vapour, but is updated in all other regards. The main design features include a power button, rapid charge USB port, removable and refillable reservoir for gassing fluid. An important aspect of the Apisolis design is the special vapour formula sold with the smoker. The “NATIVE” formula is marketed as a more natural and healthy alternative to smoke based bee sedation devices. According to comments from Apisolis, the “NATIVE” gassing fluid consists of an organically sourced corn syrup base, mixed with essential oils. This formula is FDA certified and has a patent pending.The Apisolis crowdfund page is now closed, but the price for the STARTER pack is listed at $129.00 CAD, which includes one Apisolis unit and one bottle of NATIVE formula vapourizer fluid.

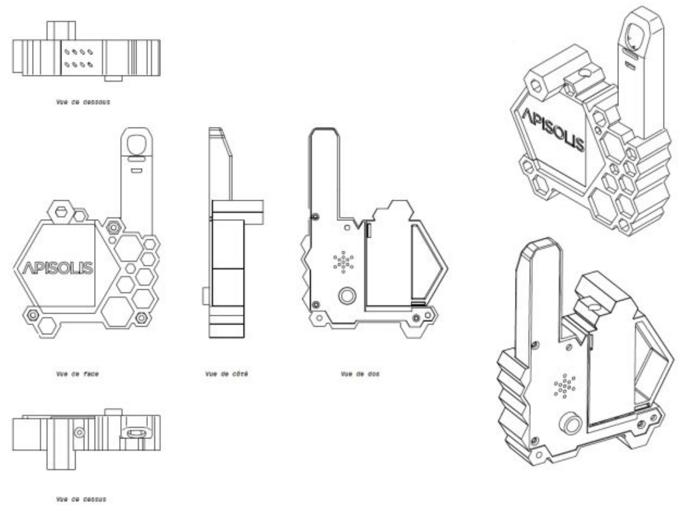


Figure 3.1. Render of the Apisolis vaporizer. Figure 3.2. Design sketches of the Apisolis vaporizer and fluid reservoir unit.

The key idea from the Apisolis design which we wish to implement, is the use of a vapourizer based design. Switching from the combustion based benchmark design to a vapourizer unit will allow a customizable vapour formula, which is healthier for bees and humans.

Propane Insect Fogger

A propane insect fogger uses combustion to create a steam vapour to treat bees. This device has been utilized for varroa mite treatment, but this design could alternatively be used for bee sedation purposes. A propane based design ignites gas in a “burner assembly” and pumps liquid through coils surrounding the assembly, effectively vapourizing the liquid. The vapour is then emitted through a nozzle, which can be directed in an efficient manner. This device is handheld, proving somewhat maneuverable, but due to the extremely hot burner assembly it must be handled with precaution and attended at all times. According to the manufacture Scintex Australia, the assembly and ignition sequence for starting the fogger is a multistep process which cannot be activated immediately in emergency situations.

Previous McGill Capstone

A former intern for our mentor Dr. Lefsrud experimented with design and building a bee vapourizer as well. Kitti Hsiang, the intern, tackled the problem via two different approaches; using a powdered smoke bomb and a vapourizer.

The smoke bombs in question were created using a mixture of colouring crayons, potassium nitrate, sugar and baking powder (Hsiang, 2016). Hsiang got this recipe from an online tutorial and used that as her bases for the smoke bomb powered bee smoker. The ingredients were mixed and baked until they resembled crushed chalk. Hsiang mentions preparing the mixture was time consuming and labour intensive (Hsiang, 2016). When the mixture was lit they produced a considerable amount of smoke, however there was no way to interrupt the smoke emission or to efficiently direct the smoke. Additionally, it is only possible to use this method once as the mixture was turned to ash once it had finished burning, and the remains took a long time to cool.

The basis of Hsiang's vapourizer design was that of a handheld e-cigarette vapourizer. Hsiang's report notes the use of propylene glycol and vegetable glycerin as the two main fuels for her design. Through deconstructing and understanding a vapourizer, she was able to design and prototype a vapourizer of her own. This design consisted of a heating element, metallic plate, and fan. Ideally the metallic plate would heat the element to the temperature at which the liquid could be dropped on and vapourized, while the fan pushes the vapour in the correct direction. The results revealed the fan was too weak to move any considerable volume of vapour. Also, the plate and heater were not powerful enough to reach an appropriate temperature to achieve the requirement vapour production, taking about two minutes (Hsiang, 2016) to hit required temperature.

4.3 Applicable Standards

Working Residue Levels in Honey

Under the Canadian Food Inspection Agency (CFIA), both domestic and imported honey are sampled and must comply with Food and Drugs Act and Regulations. The samples are tested for Working Residue Levels of a number of veterinary drugs that are approved for use in other species but are detected in imported and domestic honey. Honey does not have any Maximum Residue Levels except for an antimicrobial drug used to treat American Foulbrood infection, oxytetracycline (CFIA, 2012). The residue level guidelines are put in place to combat the "extra-label" use of these antimicrobial as they find their way into honey and other food products (CFIA, 2012). The current Maximum Residue Level for oxytetracycline in honey is 0.3ppm (CFIA, 2012). Beekeepers use these veterinary drugs to fight off microbial infections and diseases in their beehives as there are little to no approved veterinary drugs available to them. The residues of these drugs found in honey can pose a health risk for human consumption and are in violation of the Food and Drugs Act and Regulations.

This regulation provides the framework necessary to combat the rise of drug resistance via food consumption, as well as facilitate tracking down the source of the use of these drugs. However, it has very little impact on the development of our project because the gassing fluids being considered in this design do not use any sort of antibiotic. The emissions from these fluids will contain mostly water and sugar. This standard does not change our design in anyway but can potentially have some ramifications in the future if the design is changed to accomodate a fluid that contains an antibiotic such as those used to defend against mites.

Consumer Product Safety Act

The purpose of the Canada Consumer Product Safety Act is “to protect the public by addressing or preventing dangers to human health or safety that are posed by consumer products in Canada [...]” (Govt. of Canada, 2018). This act outlines the necessary requirements needed to manufacture, import or sell a product to consumers within Canada, to prevent adverse health effects. The act outlines topics like advertisement, labeling, packaging, and preparing necessary documentation. One key aspect of this act are the sections outlining the preparation of documentation for review by the Ministry, and performing tests, studies and compiling information that the Ministry deems necessary to review the respective product (Govt. of Canada, 2018). The Ministry may request any of these tests or studies before someone is allowed to manufacture or import a consumer product.

After reviewing the Consumer Product Safety Act, our team has determined that the most important aspect of this act in regards to our design is that the Ministry is able to request tests and studies to see if our product passes regulations. This section has the biggest impact on our design as it defines the boundaries of what is acceptable to have in a device. While the definition of what constitutes a safe consumer product is quite broad, as per the act it is defined as “a danger to human health and safety”, it has severe limitations on what our design can be. Our design will fall within the broad guidelines of not causing any danger to human health as that is not our objective. As such, this act has little overall impact in the development of our project as causing harm was never the objective.

Tobacco and Vaping Products Act

The Tobacco and Vaping Products Act states its purpose to “regulate the manufacture, sale, labelling and promotion of tobacco products and vaping products”. This Act covers topics such as the standards, access, labelling, and promotion of tobacco and vaping products. Furthermore, enforcement, offences and punishment are outlined for those who fail to this Act.

Reviewing the Tobacco and Vaping Products Act allowed us to determine if our design falls under this jurisdiction. In this document, a vaping product is defined as “a device that produces emissions in the form of an aerosol and is intended to be brought to the mouth for inhalation of the aerosol”. According to this definition, our bee sedation device would not qualify as a vaping product, because it is not intended to be inhaled by the user. Be that as it may, it is our intention to design our product to be as safe as possible for the user, so that unintentional inhalation does not result in any lasting harm. Schedule 1, 2 and 3 of the Tobacco and Vaping Products Act outline which additives, ingredients and flavours are prohibited for retail under the Act. It is our intention to conform to this prescription and ensure an adequate level of safety for our user, by cross checking our vaping fluid ingredients with Schedules 1, 2 and 3 (Gov. Canada, 1997).

Endangered Species Act

The Endangered Species Act was enacted in 1973 in the USA with its stated purpose to provide the means and framework to converse and protect any species and the ecosystem upon which it depends on to ensure its survival. A species must first be listed before it can fall under the protection of the Endangered Species Act. For a species to be listed it must meet one of the following criteria: “(A) the present or threatened destruction, modification, or curtailment of its habitat or range; (B) overutilization for commercial, recreational, scientific, or educational purposes; (C) disease or predation; (D) the inadequacy of existing regulatory mechanisms; or (E) other natural or manmade factors affecting its continued existence.” (U.S. Service, 1973). Once the species is listed, its habitat and geographical area becomes protected by federal agencies and it also prohibits any killing or maiming of these species (Knobbe, 2012).

This Act provides valuable legal framework for protecting critical species in the United States, but as it currently stands no species of bees or wasps are listed to be protected by this Act. As such, they are not afforded the luxury of being protected by federal agencies and people and companies will face no legal repercussions for harming or outright killing bees or wasps. This can be seen today with bee hive collapse happening due to the use of pesticides and neonicotinoids.

This Act does not currently apply to our design as it offers no legal guideline or punishment for emitting harmful chemicals from our device. As such, our design process was not impacted by the presence of this Act. However, as time passes the act may be amended to include various species of bees and at that time will have an impact on our design at which point our design will have to change to accommodate it.

4.4 Applicable Constraints

4.4.1. Internal Constraints

Budget

Our client has provided us with a starting budget of $500 CAD to construct and prototype our design. The client has mentioned that this budget is flexible and can be extended to a higher amount given the right reasons and circumstances. The initial budget does not exert any negative pressure on our design process as the estimated bulk cost of constructing a complete prototype is approximately $270 CAD with a per unit cost of $66.50 CAD. As the iterative construction phase transpired, components that were initially thought to be vital to the design were determined to be superfluous and can be replaced with a simpler and more cost effective choice. An example would be replacing the Arduino Microcontroller, justified as a way to regulate the batteries while charging, with a charge module that is designed and fabricated to protect batteries while they charge bringing down the cost per unit by an approximate $30 CAD. While the budget did not directly affect our decisions regarding components, it was still low enough that the incentive to save money by going with a more cost effective option was still there and did some influence.

Expertise

Expertise was an internal constraint that directly influence the design process. Throughout the construction phase of the design, decisions were made regarding the complexity of the circuit to bring it down to a level that was simple enough for our team to build it. Our team's knowledge of circuits and electrical engineering was not deep enough to build a circuit that included all of the components, relays, voltage regulators and displays that were in the initial design selection. Several circuits were drawn of increasing complexity, starting from the most basic circuit to one with all of the fancy components, and our team worked our way from the bottom until a point where all of the vital components were included but was still within our knowledge. Our team consulted the feasibility of these circuits with our mentor and professors to receive confirmation that they were indeed possible. In the end, the process of defining each level of circuit improved our design and resulted in one that includes all necessary components while removing anything frivolous that might complicate the use of the device.

Computer modelling software like Solidworks and COMSOL were other internal constraints. Our team's knowledge of these softwares was rudimentary, and required the use of online tutorials before our team felt comfortable using the software. However, this constraint did not have a significant impact on the development of the project as they were used as tools to validate the prototype. The impact the software played in the design is that they highlighted what was previously thought to be possible, and showed why they would not work. Through the process of modelling the outer shell in SolidWorks, certain geometries were shown to be impossible to construct given the criteria of the design and the dimensions that our team wanted. These softwares were useful to visually see the mistakes in our design and easily correct them.

4.4.2. External Constraints

The external design restrictions provide a framework for our design to fit within. These are limitations which are out of control of the design team, including marketplace, environment and safety.

Marketplace

Firstly, the beekeeper market place poses an external constraint, as our design must be more desirable for beekeepers than the current benchmark, without imposing an exorbitant price difference. Beekeepers may not see any issues with their current smokers, therefore our design must convince them of the inadequacy of the current benchmark. If our design has improved ease of use, safety and low maintenance aspects over current smokers then marketplace success is more likely. A major constraints to marketplace success is retail price. As shown with the bee smoker benchmark product, the retail price of a typical bee smoker falls around $90.00 CAD. Therefore, our design cost is constrained by acceptable marketplace retail prices, as our design should aim to retail at a similar value to the benchmark bee smoker. This is an obstacle for our team as there is considerably more technology in our device, which increases the per unit price to the limits of external constraint.

Environment

Our environmental design constraints fall under two categories: environmental impact of design materials and the environmental impact of our bee smoker emissions. For the former constraint, it is our aim to choose design materials with a minimized environmental impact. An example of one design choice which fits within the environmental constraints include use of rechargeable lithium ion batteries, rather than disposable alkaline cells, which minimizes unnecessary waste. The environmental constraints of the smoker limit our smoker to emitting vapour which is not inherently harmful to the environment. For external constraint purposes, the environment includes the bees and the area surrounding their hives. Similarly, our smoker emissions must not pose a health risk to the bees or the beekeeper.

Safety

When considering design safety, our external constraints ensure that our design will not harm the user, through regular use or by a malfunction. Our design must be ergonomic to not strain the user after repetitive use. An ideal design must also incorporate features to minimize overheating and battery combustion leading to user harm. The user will be in contact with the vapour emissions; it is imperative that the smoker emissions are safe for inhalation to maintain beekeeper health.

4.5 Business Opportunity

Beekeeping is important work, as ⅓ of food production relies on pollination services offered by bees (Packham, 2018). As an integral tool for beekeeping, the bee smoker is in need of an update, to bring it into the 21st century. There is a opportunity for the bee smoker design to be updated with current technologies, to operate with increased ease of use and ergonomics, at a higher safety standard, with lower maintenance requirements.

Beekeeping is a popular career in Canada, with 8483 beekeepers across the country tending to over 670 000 colonies (Apimondia, 2015). There are beekeepers in nearly every province but the prairies account for the majority of the colonies in Canada, Saskatchewan holds about 100 000 and Alberta another 280 000, and Manitoba with 74 000 (Apimondia, 2015). Together the three provinces make up roughly 67% of Canadian bee colonies. The number of colonies and beekeepers dwarfs that of Canada, with approximately 2.2 million colonies (Apimondia, 2015). In the United States, there are three main categories of beekeepers; commercial, sideline and hobbyist. Each category is defined by level of income sustained by beekeeping, with commercial being entirely based on beekeeping and hobbyist having little to no income from it. Of the number stated earlier, there are roughly 3000 to 5000 commercial beekeepers, the rest being populated by sideliners and hobbyists (Dept. of Agriculture, 2000). The commercial segment of this population would be the key demographic for marketing our device, as our design criteria would appeal most to them. With this in mind, the number of potential customers is between 11483 and 13843. This is a conservative estimate based on the assumption that only commercial beekeepers will be interested in our device and be willing to purchase it over a traditional smoker. The marketing analysis will be done with these numbers in mind to get an estimate of the break even point and payback period of manufacturing the design, including the entire beekeeping population will dilute the calculations and be overly optimistic.

5.0 Concept Generation

Concept generation allows engineers to brainstorm an infinite number of solutions to their design problem. It is a unrestricted creative platform, from which ideas can grow into products. Generating a concept for an advanced bee sedation device began by establishing what is currently available for this market. Once our team had a grasp on the market norms, we were able to generate concepts based on those ideas. Our intention was to enhance our creativity by learning all of the different concepts, and then brainstorm based on what we learned. Additionally, we explored technology which was not yet commercially available, but was in the exploratory phases. With as much background knowledge as possible and a clear outline of our design criteria and constraints, concept generation could begin.

5.1 System Level Concepts

Acting on a broad scale, system level concepts use a macro lens to analyze the different ways it is possible to solve the target goal. For this concept, three possible sources of bee sedation were explored (Lactic acid, smoke and vapour). Any of these three avenues could all be effectively employed for bee sedation.

Lactic Acid, Smoke, or Vapour

There are multiple mechanisms which can sedate honeybees. For thousands of years, the most typical mechanism has been the use of smoke. Smoke is a dependable sedation mechanism, and research shows that bee olfactory and pheromone receptors become blocked and unable to function, decreasing bee swarming and hive irritation. Despite the widespread use of smokers, some apiarists condemn the use of smoke. This is due to the presence of unwanted carcinogenic compounds released when smoking, which can taint honey and irritate the lungs.

Diluted lactic acid is an alternative to using smoke to sedate bees. More common in Europe, lactic acid has been explored as a method of controlling varroa mites, a parasite which plagues hives, attacking, attaching and sucking fat bodies from the bees. While lactic acid works against mites, it also sedates bees when used in a spray bottle. The dual benefit of spraying with diluted lactic acid comes from the combination of bee sedation and varroa suppression properties. Unfortunately, use of lactic acid requires a period of time after application before the honey can be harvested, as acidic concentration needs to decrease.

As a final option, vapour can be used to treat and sedate bees. It presents a promising mechanism for bee sedation as the gassing fluid can be customized to suit the intended activity. For those who prefer smoke, the gassing fluid can emulate combustion to produce clouds of smoke-like-vapour. Additionally, lactic acid can be used as the base of the gassing fluid. Clouds of vapour can be emitted rapidly, effectively covering the hives and sedating the bees. Lastly, vapourization does not change the chemical composition of the gassing fluid, only altering the molecular state.

Electric or Combustion Based Design

How should a bee smoker be powered in an ideal design? Our external search looked at different possibilities for solving this problem by reviewing techniques employed by current bee smokers. Some possibilities include biomass combustion, propane combustion and electrically powered designs.

Traditional smokers rely on biomass combustion to create smoke which is pumped by hand bellows to sedates bees. In this sense, this device is powered by the user as they pump the bellows. Building on this design, Stearn's patent uses electricity to blow the smoke from the canister, decreasing the user fatigue but increasing the inputs required. Younger's patent and the Insect fogger both use propane combustion to vapourize the gassing fluid. This is an effective design but still presents a fire hazard due to the flames involved. Lastly, Kitti's vapourizer and the Apisolis design both use electricity to vapourize their gassing fluid. This is a desirable choice as it limits fire hazard and electricity is currently a cheap resource for beekeepers in Quebec.

5.2 Subsystem Concepts

Subsystem concepts are outlined below holding the assumption that the final design will employ one of the three sedation mechanisms outlined above (Lactic acid, smoke and vapour). The key subsystem concepts are presented with potential solutions for each listed as bullet points.

<u>Batteries</u>
- Rechargable
- Disposable

<u>Computer</u>
- Arduino
- Battery modulation Printed Circuit Board
- Raspberry Pi

<u>User Control</u>
- Single button (on/off)
- Multiple buttons (on/off, power control)
- LCD digital display with feedback

5.3 Initial Screening for Feasibility and Effectiveness

Based on the concept generation, we wish to screen the potential solutions to our bee sedation problem. Once the feasibility and effectiveness have been settled, a concept can be selected to go forward into the design phase. The chosen method of concept screening is use of a Pugh chart. A Pugh chart allows comparison of multiple concepts in reference to a benchmark. For our purposes, the benchmark is the traditional smoke based steel canister design. The benchmark is given baseline values of 0 in all evaluation, and the concepts are assigned positive or negative integer values in relation to the zero benchmark. A negative value would indicate that the concept does not meet the benchmark criteria, while a positive value would show the concept exceeds the benchmark criteria. Assigning ratings for each criteria for every concept is very important, requiring justification for each rated value.

The Pugh chart below assesses multiple devices for sedating bees when compared to a traditional smoker; the options include use of a smoke bomb, vapourizer, the patented portable bee smoker, the insect fogger, Stearn's patented smoker and the Apisolis Smoker.

			Alternative Sedation Designs											
Evaluation Criteria	Weight Factor	Traditional Smoker	Kitti Smoke Bomb		Kitti Vaporizer		Younger Patented Smoker		Propane Insect Fogger		Stearns Patented Smoker		Apisolis Smoker	
			Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted	Rating	Weighted
Ease of use	2	0	1	2	-1	-2	1	2	1	2	2	4	1	2
Ergonomic	1	0	-1	-1	0	0	2	2	1	1	2	2	1	1
Safety	3	0	-2	-6	-1	-3	-1	-3	-1	-3	0	0	3	9
Maintenance	2	0	0	0	1	2	0	0	-1	-2	1	2	0	0
Effectiveness	3	0	0	0	0	0	2	6	2	6	2	6	2	6
Cost	2	0	1	2	1	2	1	2	2	4	0	0	-2	-4
Score		0		-3		-1		9		8		14		14

Figure 4. Pugh Chart to Compare Sedation Devices

Extrapolating from the Pugh chart, an ideal design favours a delivery mechanism that combines the qualities of the Apisolis design and Stearn's patented smoker. Apisolis is the safest design as there are no flames or combustion, based on vapourizer technology. The Stearn patent was ergonomic and easy to use as the device can be held in one hand by a pistol grip and requires actuation of a single button to start and stop. We believe by working forward from these two designs we can product an effective been smoking device which can meet all of our clients criteria.

6.0 Concept Selection

Conducting an initial screening for feasibility and effectiveness allowed our team to narrow our design concept drastically. From this decision process, the feasible alternatives were narrowed down to one final concept, a vapour emitting device with bee sedation properties. With these key features in mind, we shall begin to narrow our concept selection to meet our design goals.

6.1 Data and Calculations for Feasibility and Effectiveness Analysis

Will a vapourizer based design be feasible for sedating bees? This an important question to address before allocating resources to a prototype. In this section, preliminary calculations have been conducted to determine the practicality of a electronic vapourizer for bee sedation.

6.1.1 COMSOL Simulation

Target system: COMSOL multiphysics software was utilized to determine the operational temperature and electrical potential variance of the vapourizer coil. This software was an apt choice as it is capable of integrating multiple physics simultaneously over a user defined geometry to generate the target data.

Conceptual model: For our purpose, the geometry was a helix with two protruding “legs”, which represented the coil within the atomizer. The physical dimensions of a vapourizer coil were measured with vernier calipers to ensure adequate replication in the COMSOL software. Once the geometry was created, the coil material was chosen from the COMSOL material database. Stainless steel is a very common material for atomizer coils, but that was not a material choice, so we chose to use high strength alloy steel for our COMSOL simulation. This was an inherent limitation to our model as the COMSOL multiphysics package that was available to us did not include an extensive material database.

Formal Model: Afterward finalizing the geometry and material of the model, the physics packages were applied. First, the Electric Currents physics was added, applying an electrical potential of 3.7v to one end of the coil while the opposite end was grounded (0v). The Heat Transfer in Solids physics package was added, to determine heat flux from the surface of the coil, insulating the circular tips of the wire where the voltage and ground were applied. The convective heat flux conditions were applied, and a heat transfer coefficient of 3000 W/m^2K was chosen to simulate heat transfer to a boiling liquid medium surrounding the coil (Khayal, 2017). A fine mesh size was chosen for the finite element model because our coil is relatively small in size, requiring small elements to run the simulation with relative accuracy. The default external temperature of 293.15 K was used for this simulation. The mathematical equations used by COMSOL to solve this model can be seen in the appendix in Figure 12.3 with a visual representation of this model in Figures 12.1 and 12.2.

Computational Results: The results of the simulation were presented in two graphics. The first of which gave the distribution of electrical potential through the coil, ranging from 3.7v to 0v. The second second output gave a visual representation of the temperature gradient through the coil, which ranged from 645 - 665 K (371.85 - 391.85 °C). Typical temperatures for vapourizer coils which generally range from “322 − 1008°C, 145 − 334°C, and 110 − 185°C under dry, wet-through-wick, and full-wet conditions” (Chen et al., 2018). Our simulation gave slightly higher temperature results (by 37.85 °C) than the wet-through-wick conditions which most accurately reflect a typical atomizer design.

One shortcoming of this simulation was that we were unable able to properly simulate a wet-through-wick conditions, where the coil is internally wetted from the wick but is simultaneously producing vapour which is releasing heat. If vapour production and fluid flow could be incorporated into this model, we believe the coil temperature would have been reduced to a more typical temperature range of 145 - 334 °C.

6.1.2 Power/Circuitry Calculations

Vapourizers commonly use 3.7v 18650 batteries as a energy source, which powers the atomizer and user input functions such as wattage control. In addition to the typical vapourizer components, a bee sedation device requires a mechanism which can direct the vapour towards the bees. A 5v fan was chosen for vapour emission and direction, and is added in parallel to the atomizer for the circuitry calculations below. A coil resistance of 0.15 ohms was used which is typical for high vapour producing vapourizers. Working off of two 18650 batteries, is it possible to safely power an atomizer and fan?

18650 Cells Specifications
Nominal Capacity: 2600 mAh
Nominal Voltage: 3.7v
Voltage Range: 3.3 - 4.2 v
Max Continuous Current Discharge: 25A

Circuit Specifications
Coil Resistance = 0.15 ohm
Fan resistance = 20.83 ohm

Where

$$P = Power\ output\ of\ the\ cell,\ measured\ in\ Watt\ hours\ (Wh)$$
$$V = Potential\ difference\ of\ cell,\ measured\ in\ Volts\ (v)$$
$$I = Electric\ current\ of\ circuit,\ measured\ in\ Amps\ (A)$$
$$R = Resistance\ of\ component,\ measured\ in\ Ohms\ (\Omega)$$

Rated Capacity of One Battery

$$P_{cell\ capacity} = V * I_{tot} = 4.2v * 2.6Ah = 10.92\ Wh$$
$$P_{tot\ capacity} = P_{cell\ capacity} * 2 = 21.84Wh$$

Preliminary calculations have been conducted here to establish the operational specifications. These calculations assume the batteries are fully charged to 4.2v and are connected in parallel with the circuit.

Resistance

$$1/R_{tot} = 1/R_{fan} + 1/R_{coil}$$
$$1/R_{tot} = 1/20.83 + 1/0.15$$
$$R_{tot} = 0.1489\ \Omega$$

Total Current and Current Per Cell

$$I_{tot} = V/R_{tot} = 4.2v/0.1489\Omega = 28.21\ A$$
$$I_{cell\ load} = 28.21A/2 = 14.10A$$

The amp load will be split between the two batteries in parallel therefore they will both be safely operating at 14.01A which is below their Max Continuous Current Discharge of 25A.

Total and Per Cell Power Requirements

$P_{tot\ req} = V * I_{tot} = 4.2v * 28.21A = 118.48W$

$P_{cell\ load} = V * I_{cell\ load} = 4.2v * 14.10A = 59.23W\ per\ cell$

Time of Discharge (Runtime for two cells in minutes)

$T = 60\ minutes * P_{tot\ capacity}/P_{tot\ req} = 60\ minutes * 21.84Wh/118.48W = 11.06\ minutes$

According to these calculations, one vapourizer unit could sustain 11.06 minutes of continuous discharge.

Falstad Circuit Simulation

For further circuitry calculations, we conducted a simulation using a falstad applet which allowed us to build a virtual circuit. From this circuit, the voltage, current, resistance and power could be determined for each branch. Only one power supply was added in parallel as voltage does not vary with cell charge for this simulation. Once again the voltage supply is assumed at 4.2v which is the full charged battery.
Figures of this circuit have been included below.

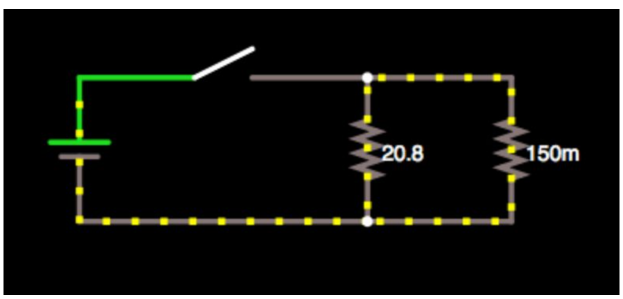


Figure 5.1. Circuit simulation with switch deactivated

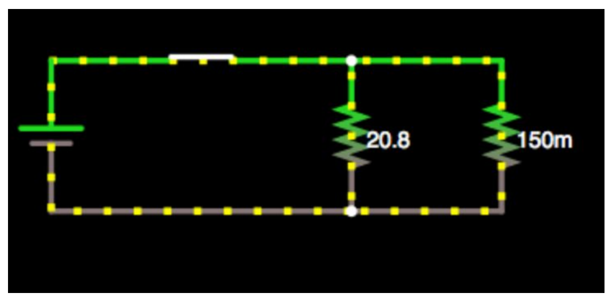


Figure 5.2. Circuit simulation with switch activated

From this simulation it was determined that the fan and the atomizer consume 0.847W and 117.6W of power respectively. Additionally, the fan and the atomizer each pull 0.202A and 28A of current respectively.

6.1.3 Fluid Flow Calculations

An important aspect of this design relies on the fan pushing air through the atomizer to direct the vapour out of the spout and onto the bees. An atomizer is typically used to vapourize e-liquid which is inhaled by the user; a typical human breath must be able to draw air through the atomizer. Ideally, the fan flow rate will be equal to or greater than a human breath, providing sufficient flow to push air through the atomizer towards the bees. To analyze the feasibility of our design we determined the flow rate of a typical human breath and compared it to a typical 5v fan flow rate of 0.28 m^3/min.

Where

$$T = Time,\ measured\ in\ seconds\ (s)$$
$$V = Volume,\ measured\ in\ cubic\ metres\ (m^3)$$
$$Q = Flow\ rate,\ measured\ in\ cubic\ metres\ per\ second\ (m^3/s)$$

Assumptions of Human Breath
Breath duration: $T_{breath} = 2\ seconds$
Tidal Breath Volume: $V_{lungs} = 500\ cm^3 = 0.0005\ m^3$
These values were suggested by Hallet and Ashurst (2019).

Inhalation Flow Rate
$Q_{inhale} = V_{lungs}/T_{breath} = 0.0005\ m^3/2\ seconds = 0.00025\ m^3/s$

Fan Flow Rate
$Q_{fan} = (0.28\ m^3/min)\ /\ (60\ seconds/min) = 0.00467\ m^3/s$
This value was obtained from the Farnell datasheets for Elina Fans.

From these preliminary calculations, we observe an approximate inhalation flow rate of 0.25L/s compared to 4.67L/s for the fan flow rate. The fan flow rate is over 18 times larger than a typical human inhalation, indicating that it is plausible to use a 5v fan to push air through an atomizer for emitting and directing vapour.

6.2 Concept Screening

Part of the concept selection process involves getting feedback from the potential customer. We met with the McGill Apiculture Association to present our idea and to learn what do beekeepers want from their smokers. The points of our meeting are listed below.

Positive Feedback

- Favourable size and shape
- Elimination of burn potential compared to benchmark smoker
- Friendly for no glove use
- Adequate for hobbyists
- Requires minimal hand dexterity

Constructive Feedback

- ABS plastic lacks grip
- Shell seams should be water resistant
- Consider addition of a finger loop
- Battery charge may not last for industrial applications

The feedback from this meeting was very positive and the McGill Apiculture Club would like to see this design go into the prototype stage.

6.3 Concept Development and Selection

Having settled on a vapourizer based design and conducting preliminary calculations, it is important to outline the possible design complexity levels of the subsystems. The chart below outlines the possible design levels and the corresponding details, ranging from least complex to most complex.

Table 3. Hierarchical Concepts

Design Level	Subsystem Technological Details
1 (most simple)	- Utilize a simple button to start/stop vapourizer and fan - System is hard wired with fixed voltage and power - Batteries are alkaline (non-rechargeable), require replacing when dead
2	- Utilize a simple button to start/stop vapourizer and fan - System is hard wired with fixed voltage and power - Batteries are lithium-ion (rechargeable), but must be removed from device to be recharged
3	- Utilize a simple button to start/stop vapourizer and fan - System is hard wired with fixed voltage and power - Batteries are lithium-ion (rechargeable), and the device can be plugged in to a wall outlet to receive charge, utilizing overcharge protection module
4 (most complex)	- Implement a microcomputer to control relays which start/stop the vapourizer and fan - The microcomputer can modulate power to the atomizer to control the atomizer temperature - Batteries are lithium-ion (rechargeable), and the device can be plugged in to a wall outlet to receive charge, utilizing overcharge protection module

This hierarchy of design possibilities integrates varying levels of complexity and functionality. However, the internal and external constraints of this project limit the prototype construction to achieve basic functionality. Specifically, our circuit design and program development expertise limited us from utilizing a microcomputer for battery modulation and variable wattage control. We have decided to build a level 2 prototype to demonstrate the “proof of concept”. To supplement this basic design, recommendations have been added for how the design could be further enhanced, if full scale market production was the goal.

7.0 Final Design

For the final prototype design, we settled on iteration 2 which is one step up from the most simple option within the hierarchy of design complexity (above). This iteration uses a simple button to initiate startup and is released to stop the device. The system is hard wired, operating based on fixed resistance and is intended to work within the nominal battery voltage range. Lastly, we have chosen lithium-ion batteries as our power source as they are rechargeable, have a suitable power output, and are standard in the vapourizer industry.

7.1 How does it work?

7.1.1. System Level

Our device is designed to be as simple as possible for the costumer to operate. To operate the device, the user has to ensure the batteries are fully charged and the atomizer is filled with appropriate gassing fluid. Point the sedation device in the direction of the bees and press and hold the button.When the button is triggered, the fan and atomizer will power on simultaneously. The coils inside the atomizer begin to vapourize the fluid while the fan pushes air through the ventilation ports of the atomizer moving the vapour out of the device. The fan will push enough air through the atomizer to simulate the suction normally provided by user inhalation which is typical for electronic cigarettes use. The atomizer and fan are placed parallel with the batteries in the circuit so that both components receive equal voltage. Once the bees are adequately sedated, let go of the button to power off the device. After a days use of bee smoking, simply open the smoker to remove the batteries and plug them into a charger to repower them.

7.1.2. Sub System Level

There are five key components implemented on the subsystem level. These systems include the atomizer, batteries, structure, gassing fluid and fan. Each subsystem is outlined below, discussing the important design considerations.

Atomizer

The atomizer is the central component to any vapourizer and it is important to choose one that will meet the requirements of the design. Vapourizers for smoking require an acceptable taste. In the case of building a handheld bee vapourizer, taste is not as important as usability, as well as vapour production, reliability and economics. For a design of this scope and size there are two possible choices for atomizer designs that will satisfy the design criteria. The choice is between a Rebuildable Dripping Atomizer (RDA) and Rebuildable Tank Atomizer (RTA), the fact they are rebuildable is no coincidence. Being rebuildable, it is possible to change the number and material of the coils as well as the wicking material. Out of the two possible selections, the RTA is the optimal choice for this design as it meets all the constraints.

Our team decided on the RTA style of atomizer over an RDA because the tank is placed directly on top of the atomizer itself. This choice simplifies design, as using dripping method requires secondary storage tank. The RTA style also minimizes the risk of burning the coils as the wicks and coils are fully submerged in the liquid at all times, meaning they will almost never be dry enough to burn out. Additionally, since the tank is attached to the atomizer it is simple to refill as needed without having to move anything. The ability to change the coil and wicking material is crucial to the design process as it allows us to adapt our design down the line if needed.

The Vaperz Cloud VCMT RTA meets the functionality specifications and has a 6mL capacity tank. A 6mL capacity is considered above average storage capacity, holding enough gassing fluid for a full day of working with bees. This atomizer was readily available from a local retailer and suited our purpose so we chose to purchase it for this design project. The Vaperz Cloud specifications are included in the appendices in Table 7.

Stainless Steel is chosen as the coil material for two reasons; it is the only material that is capable of operating under both wattage control and temperature control, and it is commonly found in retail outlets. The wicking material of choice is cotton, which is easy to find and works well in many atomizer configurations.

Batteries

When choosing a battery, there are two major design consideration. The first thing to consider is which type of battery to use, specifically, what chemical composition is favourable for a portable handheld vapourizer. Secondly, the specifications of the battery cells must meet the amperage, voltage and current demands of the vapourizer unit.

For portable, handheld electronics, lithium batteries are very common. This is because they are the lightest, have the greatest electrochemical potential, and have the largest energy density to weight ratio (Wu, 2015). For the purpose of a vapourizer, there are three kinds of lithium batteries to choose from, ICR, IMR and Hybrid cells. The difference between these three types is the chemical composition, as each utilizes a different chemistry for their cathode. Lithium Cobalt Oxide (ICR) delivers the highest specific energy, which means they have the highest rated storage capacity. Unfortunately, ICR cells are the most dangerous, and often the most difficult to work with. Due to the finicky nature of ICR batteries, they require a protective circuit to keep them operating at the nameplate ratings. Lithium Manganese Oxide (IMR) cells offer a popular alternative choice for vapourizers. IMR cells are safer than ICR, allowing high discharge of current at low temperatures. Additionally, IMR cells require minimal protective circuitry due to their stable nature. Building upon the safe chemistry of IMR, hybrid cells, offer a more favourable option as they incorporate nickel into the chemical composition. A Lithium Manganese Nickel (INR) hybrid cell retains the safety and low resistance of manganese cells while with high energy storage due to the nickel. INR cells are the preferred choice, requiring little protective circuitry while giving reasonably high capacity and discharge current.

The second design consideration for batteries, is whether they will meet the requirements of the device. In what regard does the battery affect the usability of the device? Firstly, it must hold enough charge to power the device for an entire day of working with honeybees. The components drawing power from the battery include the atomizer, fan, processing unit and potentially an LED battery charge indicator.

As described by Wu (2015) Lithium batteries are rated by storage capacity, amperage and voltage. Comparative research was conducted to determine what typical vapourizers uses for batteries. Firstly, the storage capacity, or power requirements, are calculated as milliamp hours (mAh), which indicates how long the vapourizer can be used for. This can range from roughly 2000mAh to 4000mAh. Secondly, the amperage of a vapourizer indicates how long is the maximum continuous discharge, ranging from around 15A to 30A. Lastly, the voltage of a typical vapourizer battery is 3.7v, which has a working range from 4.2v to 3.2v. The vapourizer must not be over or undercharged as this can damage the battery, resulting in fire or explosion. The power, voltage and peak continuous discharge are values that will be calculated when formulating the final bee sedation vapourizer design.The specifications of our chosen battery, the Sony VTC5A Cell, are outlined in Table 8.

Structure

There is one main constraint regarding the size and shape of the outer shell of the handheld smoker; the design and all of the components must fit in the hand of an average person. Beyond designing an ergonomic shape, one must consider the construction material too.

Our team has decided to 3D print the outer shell, using Acrylonitrile Butadiene Styrene (ABS) plastic as the printing material. ABS plastic is the most commonly used printing material due to its great material properties. Specifically, ABS has favourable strength, ductility and thermal stability (Giang, 2015) as shown in Figure 11 in the appendices. ABS was chosen over the biodegradable Polylactic Acid plastic, another common option, because the benefit of a more durable material outweighed the benefit of a biodegradable material. The tensile strength and resistance to bending are beneficial for our design because it will enable it to withstand moderate damage inflicted. The shell is printed approximately 7 cm in diameter and 20 cm tall, in order to fit all of the internals whilst remaining within the boundaries set by the design parameters. Also, there will be threading incorporated roughly half way into the full length, so that the container can be unscrewed to easily access the electronics, allowing easy refill of the atomizer. The top end of the structure will be tapered from the base of the atomizer to the tip, forcing air through the atomizer. The tapered section will also aid in the directing the fluid flow. Lastly, the shell will be printed vertically as to reduce the number of 3D printer supports.

Gassing Fluid

The gassing fluid effectiveness will have the greatest weight in determining the market success of this bee sedation device. As discussed previously, research points in many directions for an adequate source of bee sedation.

When interviewing the president of the McGill Apiculture Club, she testified that a diluted lactic acid mixture was a very popular spray for bee sedation in Norway. Further online research confirmed her statement, but there was a lack of peer reviewed literature to give objective truth on the matter. User testimonies suggested that not only did the lactic acid solution calm the bees, but also acted to protect the hives from varroa mites. Alternatively, a mixture containing liquid smoke was cited by the Patented Bee Smoker to sedate bees. The liquid smoke is said to be mixed with glycol, which is commonly used in the vapourizer industry (Sheskey et al. 2017). Vegetable glycerin is another option with which liquid smoke can be mixed. Beekeeper testimonies suggest that liquid smoke effectively deters bees from stinging, and can also be applied topically after a sting has occured to prevent surrounding bees from smelling any alarm pheromones.

To determine which is the more suitable gassing fluid, experimental trials should be conducted to test diluted lactic acid against a liquid smoke mixture. Also, these trials should also consider the health of humans and bees. The results of these trials will decide what gassing fluid best suits the purpose of a bee sedation device.

Fan

The main requirement for a fan is to produce adequate air flow to create enough pressure to push the vapour through atomizer and into the beehive. According to our calculations the fan must have a flow rate greater than 0.25L/s to adequately push the vapour through the atomizer. We have chosen an Elina 5v fan which is detailed in Table 9.

7.1.3. Instruction/Maintenance Manual

User maintenance includes replacing the coils and wicking material of the atomizer, charging the batteries via USB port and in the scenario where the batteries are defective replacing them with new ones. Charging the device is done by connecting a USB cable to the charging port located on the device. The internal charge module will ensure that the batteries are not subjected to over charging, and will regulate the current and voltage applied to the system. The batteries are accessed by disconnecting the slip joint located midway up the bottom half of the shell. From there the batteries are housed in a simple battery holder and can be removed normally; 18650 batteries are used in this device and can be purchased online or at most electronic retailers. The atomizer can be accessed by unscrewing the top portion of the shell, and removing it from its support system. Once the atomizer is dismounted from its support, the tank can be filled by pouring the gassing fluid into the opening. Replacing the coils requires the tip and tank removed, then unscrewing the fasteners holding the coils in place. Once this is done place the new coils into the posts and tighten the screws, then feed wicking material through the center of the coils. Next, place the tank and tip back and proceed to fill the tank with fluid. Finally, put the atomizer back on to its support bracket before next use.

7.2 Cost and Manufacturing

Our device is a mixture of “off the shelf components”, purchased from a local retailer, and parts fabricated in house. The in-house fabrication will consist of printing the outer shell and atomizer support piece and wiring the system together including soldering the circuitry connections. Our prototype shell was manufactured via additive 3D printing and the results are more than satisfactory, so our team suggests to continue with this method of production for small scale manufacturing, potentially upgrading to die cast molds if production were to reach an industrial scale. Most of our electronic internals were purchased off the shelf including the RTA atomizer, coils and wicking material, 18650 batteries, 5V fan, 18-gauge copper wires, battery holder and button. The off the shelf variants of these components satisfy the criteria of the design and therefore in-house design and manufacturing is not needed for these thus saving time. The estimated cost per unit is $128.68. This includes the prices of the off the shelf components, 3D printing filament, and 1.5 hours of labour at a wage of $20 per hour. A list of the components can be seen in the Bill of Materials. If our team were to manufacture it ourselves, the price point would drop to $66.50 as we would not include the cost of labour profiting directly from each unit sold.

Manufacturing can be broken down into 3 distinct steps. The first step is to print the outer shell and support piece from the SolidWorks CAD files that our team has designed and modelled. The shell is made from 3 main pieces: the lower part of the shell which houses the batteries, charging port and button, the midsection which will hold the fan in place, and the top cone in which the atomizer will sit. The dimensions do not need to be changed from the files provided, but the orientation of the pieces must be changed in respect to the capabilities of the printer. We suggest printing them upright one piece at a time to reduce the number of printing supports and the chance of printing error. Once the pieces are finished printing, inspect for any discontinuities with the printing and remove excess support material.

The second step is to wire the internal components together. The atomizer with its 510 connectors should be at one end of the wiring while the batteries at the other end, this is to ensure that there is sufficient length of wiring to run from the bottom of the shell to the beginning of the top cone. The two 18650 batteries with their holders should be set up in parallel so that they have an output of 3.7V, enough to power the components but not run the risk of overheating the fan and atomizer. Furthermore, the fan and atomizer should also be wired in parallel to receive equal voltage amongst them. This setup can be seen in Figures 5.1 and 5.2. Once this laid out properly, solder the connections making sure to tape the connections to avoid the risk of short circuiting the batteries potentially causing an electrical fire.

The final step is to fit the components and wiring into the shell. Start by drilling a hole in the base for the button and then secure the batteries, charging port and button in place with adhesive with the button poking through the shell. Next place the fan in the midsection piece which slides into the base via the slip joint. Finally thread the 510 connector through the flat support piece and screw the atomizer onto the connector. The support piece will sit on top of the topmost part of the midsection piece. Finally screw the cap on using the provided threading. The construction is now complete.

ABS plastic is the suggested material for the shell and atomizer support, as it is common, inexpensive and strong. The tolerances of the shell are made to fit each component within 1-2 mm of the dimensions provided by the components. This tolerance is quite high due to the inherit tolerances associated with a 3D printer.

Therefore tolerances will be range depending on the quality of 3D printer used, with lower quality printers potentially requiring some filing or sanding to make the pieces fit.

7.3 Design Drawings and Bill of Materials

As mentioned previously, the outer shell is separated into three main sections with a fourth support piece. The three main sections can be seen in the appendix in Figures 13.1, 13.3 and 13.4 with the additional support piece in Figure 13.2. The dimensions seen on this Figures are made to fit the off the shelf components that our team used during the iterative design and construction process, the tolerances associated with these dimensions are that of the resolution of the chosen 3D printer and the minute intrinsic error with vernier scale calipers. The off the shelf components can be seen in the bill of materials below, only the shell and support pieces were designed custom fit by our team. The total cost to source the material needed for one unit is $60.38 but a safety factor of 10% is applied to account for pricing differences and market fluctuations, results in an estimated cost of $66.50. Prices and receipts for the components sourced from local electronic shops can be seen in the appendix in Figures 18.1 and 18.2.

Table 4. Bill of Materials

No.	Part	Quantity	Description	Weight (g)	Cost
1	Shell and Support[1]	1	ABS Plastic 3D Printed Shell and Support Piece, 6cm dia. by 19 cm height	129	$3.40
2	Atomizer [5]	1	VCMT RTA Atomizer clone, 25mm dia. by 63mm height	92	$14.65
4	Battery [2]	2	Sony VCT5A 18650 Lithium Ion Batteries	48	$12.99
5	Wicks [2]	0.5g	Cotton wicking material for atomizer coils	0.5	$0.43
6	Coils [2]	2	32 gauge Stainless Steel sub ohm vapourizer coils	2	$16.00
7	Fan [4]	1	5V 40mm by 40mm DC fan	20	$3.44
8	Battery Holder [4]	2	Single 18650 battery holder	25	$4.58
9	510 connector[3]	1	Metal connector fits on bottom of atomizer, connects to circuitry	10	$4.69

10	Copper Wires [4]	30cm	18 gauge copper wiring	5	$0.20
Total	-	-	-	-	$60.38

1 Note : See reference (Amazon, 2019c)
2 Purchased from local retailer, BMY Vape, see figure 18.1
3 Note : See reference (Amazon, 2019b)
4 Purchased from local electronics store, Access Electronique DDO, see figure 18.2.
5 Note : See reference (FastTech, 2019)

7.4 Design Validation

Upon completion and assembly of the prototype, we were able to validate and test our design. The following table compares our results to the five target specifications outlined in section 3.0.

Table 5. Tests for Validation of Target Specifications

	Start up	**Ergonomic**	**Ease of use**	**Safe**	**Vapour production**
Information Needed to Perform Test	Does it start quickly and easily?	Is it ergonomic for use by beekeepers?	Did we achieve minimal complexity?	Is there a threat to the user?	Is the vapour production adequate for sedation?
Design of Test	Actuating the button	Assessment by McGill Apiculture Association	Assessment by McGill Apiculture Association	Experimental tests and visual inspection	Assessment by McGill Apiculture Association
Metric	Time	Approval/ Disapproval	Approval/ Disapproval	Trial and Error	Approval/ Disapproval
Measurement System	Does it start? Is it instantaneous?	Fits within hand? Comfortable for extended use?	Able to use it without in depth instruction?	Can it run without error for extending time?	Visual assessment of vapour production
Results	Meets	Needs improvement	Meets	Fails	Meets

Once initiated, the system produced and emitted substantial amounts of vapour. Figure 17 in the appendices provides an example of the vapour production. For further validation of these results, a set of trials should be conducted to assess the quantity of vapour produced and test the limit of the device battery life. Concurrent to design test trials, a bee sedation gassing fluid can be developed and tested to assess what gassing fluid properties are best suited for bee sedation.

Our team considers the initial design a success as a potential client, the McGill Apicultural Association, remarked that there was plenty of vapour production for bee sedation. In addition, our mentor and client, Dr. Mark Lefsrud, was pleased with the results and believes that this project should continue.

7.5 Design Considerations

7.5.1 Social Considerations

A primary social consideration is the overall well being and health of the beekeeper using the vapourizer. The handheld vapourizer design must ensure that the users are not exposed to any potentially dangerous emissions. For this reason, our team thinks that either propylene glycol or vegetable glycerin will be viable vapourizing liquid, as it has been shown to have little effect on human health. Comparatively, the combustion of biomass has been reported to be one of the main causes of respiratory symptoms such as Chronic Obstructive Pulmonary Disease (Polati et al, 2002). The report states that inhaling any amount of biomass combustion emissions has a significant effect on lung functionality. While the biomass burning bee smoker does not emit a great amount of smoke, any exposure to these emissions can have negative effects on the health of the user. Such that a vapourizer emits nearly no CO2 compared to a traditional smoker (Britton et al, 2014), this is a direct health benefit for the user by lowering their risk of respiratory problems and decreased lung function.

Another concern is whether a life long beekeeper will be open to learning a new device after having spent years familiarizing himself with the previous one. By designing the handheld vapourizer to be as simple as possible and requiring little user input makes this design as approachable as possible for those who are switching over. Our product benefits the society of beekeepers, making the job easier. This updated design plans to reduce the hassle of startup and cool down, while also reducing the number of bee stings. There are little social concerns about the use of our products outside of the beekeeping industry, as it is not a mass consumer product and will only appeal to a niche market. Our design will adhere to the standards for consumer grade electronics and the standards set out by health organizations regarding vapour inhalation in order to prevent harm to the user.

One social consideration is the quality of the final product; honey. According to the Apiculture Association here at Macdonald Campus, honey can hold a smoky flavour if beekeepers use the smoker too much, as the smoke gets into the honey. This will not be a problem with the vapourizer design as the fuel quickly disperses and has no taste after it is vapourized. If a combination of Propylene Glycol and “Liquid Smoke” was used, the concentration of the liquid smoke would not be high enough to rival the scent of a traditional smoker.

Risk Factor Matrix

The following table presents nine potential Risk Factors associated with the use of a vapourizer based bee sedation device. The Risk Rank ranges from 1-3, which indicates the likelihood and the danger level. Risk Contributors describe what increases risk while Mitigation Procedures identify what can decrease risk.

Table 6. Risk Factor Matrix

Risk Factor	Risk Rank	Risk Contributors	Mitigation Procedure
Battery Combustion	3	-Faulty battery -Improper charging -Running above rated values	-Install LED indicators for low/high power -Install power charge module
Vapour Inhalation	1	-Inhalation of harmful chemicals -Being too close to vapourizer	-Beware of wind direction -Use the recommended gassing fluid
Shell melting	1	-Excessive extended use of vapourizer -Overheating of coils	-Minimize vapour discharge duration
Bee Stings	2	-Atomizer tank is empty -Improper delivery of vapour	-Personal Protective Clothing -Exercising proper beekeeping techniques
Shocked by batteries/faulty wiring	1	-Improper installation -Exposed Wiring	-Compartmentalize wiring and battery -Insulate wiring
Touching hot atomizer	1	-Attempting to refill right after use	-Temperature control -Wearing gloves
Contaminated Honey	1	-Chemical composition of the vapour	-Wait after applying vapour -Don’t discharge more than necessary
Detrimental Effects to Bee Health	1	-Vapour affecting intestinal bacteria	-Discharge only enough to sedate bees

7.5.2 Environmental Considerations

The purpose of this project is to design an instrument for beekeepers which can effectively sedate bees. Our goal is to fulfill this purpose while minimizing impacts to the environment. Our functional unit of interest is defined as one bee sedation vapourizer, of which the major components were outlined as the atomizer, battery, structure, gassing fluid and fan. Each of these components incurs an environmental impact from the raw material extraction through to the end of its useful life. Life Cycle Assessment (LCA) is a useful tool used to consider the impacts of a product over its entire lifetime. We conducted a LCA, which allows us qualitatively and quantitatively assess the environmental impact of one functional unit from “cradle to grave”. A “cradle to grave” analysis considers the impact from material extraction to end of useful life.

For this LCA, the product system boundaries encompass the material use, energy use, greenhouse gas (GHG) production and waste production during the cradle to grave period of the functional unit. We have qualitatively assessed this system with Figure 6, a flow chart of the aforementioned components within the system boundary.

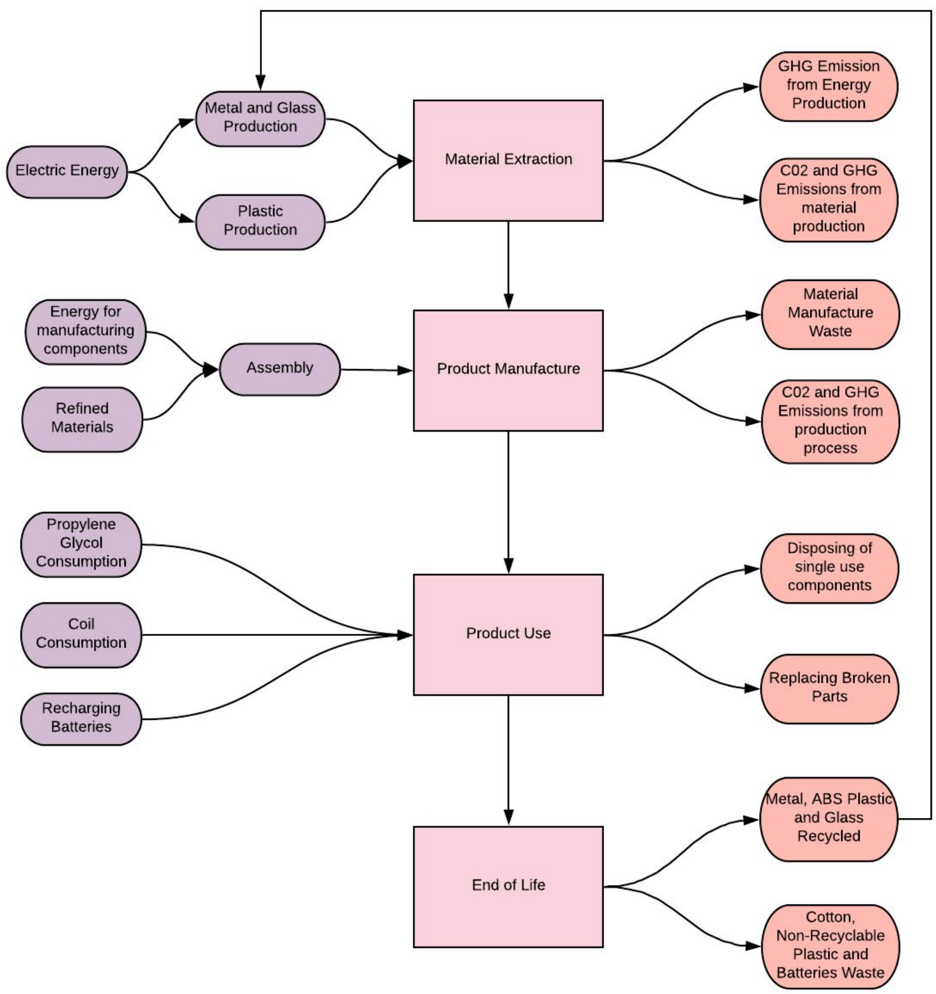


Figure 6. Qualitative flow diagram of material use, energy use, GHG production and waste associated with production of one functional unit.

From the figure above we can see the breakdown of the environmental impacts at each step of our product life and work towards a quantitative environmental assessment. When implementing an engineering design, it is important to consider whether the materials used are recyclable. Our vapourizer based design can be simplified into three main sections: structural shell, batteries, and atomizer. For the shell, 3D printed ABS plastic has been chosen which can be recycled and reused to 3D print again. In this regard, 3D printed supports and end of life shells, can be shredded and heated for reuse because it is a thermoplastic, not a thermoset. Lithium-ion batteries are used in the vapourizer to store the energy necessary for operation. These batteries accepted by many recycling facilities, but cannot be directly recycled for reuse in another functional unit. Lastly, the atomizer is the most complicated part of the vapourizer unit. The atomizer has three main parts, a cotton wick, stainless steel body and glass fluid chamber which each have a specific environmental impact. The stainless steel and glass components can be recycled, while the cotton wick can be composted because it is organic.

To quantitatively assess the impact of the functional unit, we determined the GHG emissions associated with the Cradle to Gate, Useful Life, and End of Life periods. The LinkCycle LCA Tool found on SourceForge.com provides an outline to calculate how many kilograms of CO2 are emitted for one functional unit, splitting it into the appropriate life cycle periods. We compiled generalized CO2 emission data for each of the major materials used in our design and implemented them in the LinkCycle LCA Tool. One important assumption when using LinkCycle was that the end of life impact represents the carbon emissions expelled to replace or recycle the materials back to a usable state. Our findings are presented in Figure 7.1 and 7.2 below. A more detailed breakdown for these values can be seen in Figure 19.1, 19.2 and 19.3 in the appendix.

	Emissions from each phase
Cradle to Gate	1.94825
Use Phase	0.0322692
End of Life	1.509245
TOTAL	3.4897642

Figure 7.1. Kg of CO2 emissions for each phase of the functional units life and the total emissions over the entire life

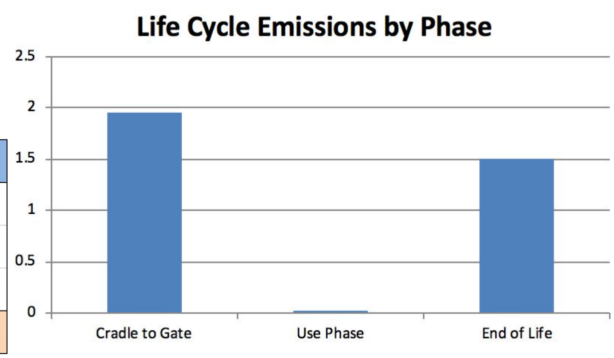


Figure 7.2. Visual representation of Kg of CO2 emissions for each phase of the functional units life

From our LinkCycle LCA Tool we found there is roughly 3.5 kg of CO2 emitted over the lifetime of our product. We see the majority of CO2 emissions are incurred during the Cradle to Gate phase (1.94825 kg) which includes material extraction, processing and product manufacturing. The least amount of emissions are generated during the Use Phase of the product (0.0322692 kg), as the only requirements are electricity for charging the batteries. The End of Life phase considers the emissions to replace the product (1.509245 kg), which is less than the initial production emissions as the stainless steel, ABS plastic, glass and copper can be recycled. Two materials from our design which cannot be recycled are the lithium ion batteries and the cotton wick. It should be noted that sourcing the lithium ion batteries needed for this design contribute 1.056 kg of CO_2, accounting for over half of the emissions incurred during the entire Cradle to Gate period, and once again at the End of Life period when they need replacing. If there were a method for recycling these batteries, it would substantially decrease the CO_2 emissions associated with this product.

One assumption of this model is that the device is being charged three times a week, from April to end of October during the beekeeping season. Another assumption of this model is that the product is being used in Quebec. Instead of relying on combustion to produce smoke like a traditional smoker, the new design charges the batteries from a 120v wall outlet using power from the energy grid. Depending on the location of the user, this energy could have been produced in many different ways. In Quebec the electricity is generated from Hydroelectric dams, which is a relatively clean electricity source, generating 0.02 kg of CO_2 per kWh of energy produced (Hydro-Quebec, 2018). In other regions of the world, the CO_2 released per kg of CO_2 emitted will vary.

One inherent limitations of our model is that we cannot access very comprehensive LCA databases which give more accurate info regarding carbon emissions and environmental impact for material processes and flows. Another limitation is that we are not privy to the transportation emission data of the components we sourced, and were unable to add this to the LinkCycle Tool.

We recommend that if this design was taken to market, a more comprehensive LCA is conducted after consulting with manufacturers. This would allow specific details regarding material sources and manufacturing processes to be incorporated.

Another important environmental consideration besides CO_2 emissions is the effect of the vapour product on the treatment area. Traditionally, bee hives are situated outdoors, in vegetative areas where the bees have access to flowers. When using smokers, the smoke drifts and blows around diffusing the scent to the surrounding area. Traditional smokers burn biomass releasing chemicals including carbon dioxide, carbon monoxide, nitrogen oxides, ammonia, and soot, all of which add to air pollution. Additionally, smoke is an irritant for beekeepers, proving uncomfortable to inhale and leaves a lingering scent on the beekeeper. Conversely, vapourizing does not change the chemical composition of the gassing fluid, it changes the energy state of the molecules from liquid to gaseous. For the vapourizer design, the gassing fluid is completely customizable, meaning that a beekeeper can choose a gassing fluid that suits their needs and the environment. Additionally, vapour does not have any fine particulates, like soot, which would pollute the air, degrading atmospheric conditions.

The health effect of our product to bees is considered an environmental impact. Smoke has been used to calm bees for thousands of years, with no observed adverse health effects to bees. Some claims that there are negative health consequences from using smoke, but no peer reviewed articles to confirm these suspicions. Smoke blocks the pheromone receptors and decreases olfactory sensation, but only takes 10-20 minutes before the pheromone receptors will return to normal. Vapour released from our product will act in a similar way to sedate the bees. There is little research to suggest whether vapour poses a health risk to bees. We suggest that before conducting trials with our prototype vapourizer, the gassing fluid used will be analyzed for compounds posing a considerable threat to bee health.

7.5.3 Economic Analysis

The industry standard bee smoker is the Mann Lake HD450 is outlined in Table 2. The HD450 retails for $89.40 CAD and is available on online markets such as Amazon. Our design will cost approximately $66.50 to produce a single unit, with a selling point of $89.77 after a 35% markup. A markup of 35% on manufactured goods is the industry average (Morgan, 2017). A detailed breakdown of the price and components can be found in the Bill of Materials section. Our selling price is similar to the Mann Lake H540, making it our direct competitor. Our design presents a more favourable choice compared to similarly priced product since it is easier to use, safer and can sedate bees in less time. Although it never went into production, the Apisolis bee smoker would have retailed starting at $127 CAD for their lowest version according to their crowdsourcing page. The Apisolis would be in direct competition with our device as it also caters to the same demographic. While there are differences between the designs, the lower price point of our device is our biggest advantage against the Apisolis.

The cost associated with producing one unit of this design is $66.50 just for materials alone. However, if our team were to manufacture and assemble the units in house it would require the purchase of a 3D printer. One such printer is the Creality Ender 3D Special Edition, which retails for $350 CAD plus tax, totalling $402.50 CAD (3D Printing Canada, 2019) and this is our fixed cost. The breakeven point of producing our device is 18 units, assuming a 35% markup on the production costs and that each unit produced is sold. After the 18 units are sold the printer will be paid off and the profits can be reinvested into more printers to increase production rates. With a low break even point of 18 units and a potential market of over 12 000 customers, the business opportunity of our team’s product is not bottlenecked by a shortage of customers and thus can be a profitable venture given appropriate marketing.

$$Break\ Even\ Point\ when\ Total\ Revenue\ =\ Total\ Costs$$
$$Fixed\ Cost\ =\ 402.5$$
$$Variable\ Cost\ =\ 66.50$$
$$Selling\ Price\ =\ 89.77$$
$$89.77Q\ =\ 402.5\ +66.50Q$$
$$Q\ =\ 17.29\ =\ 18$$

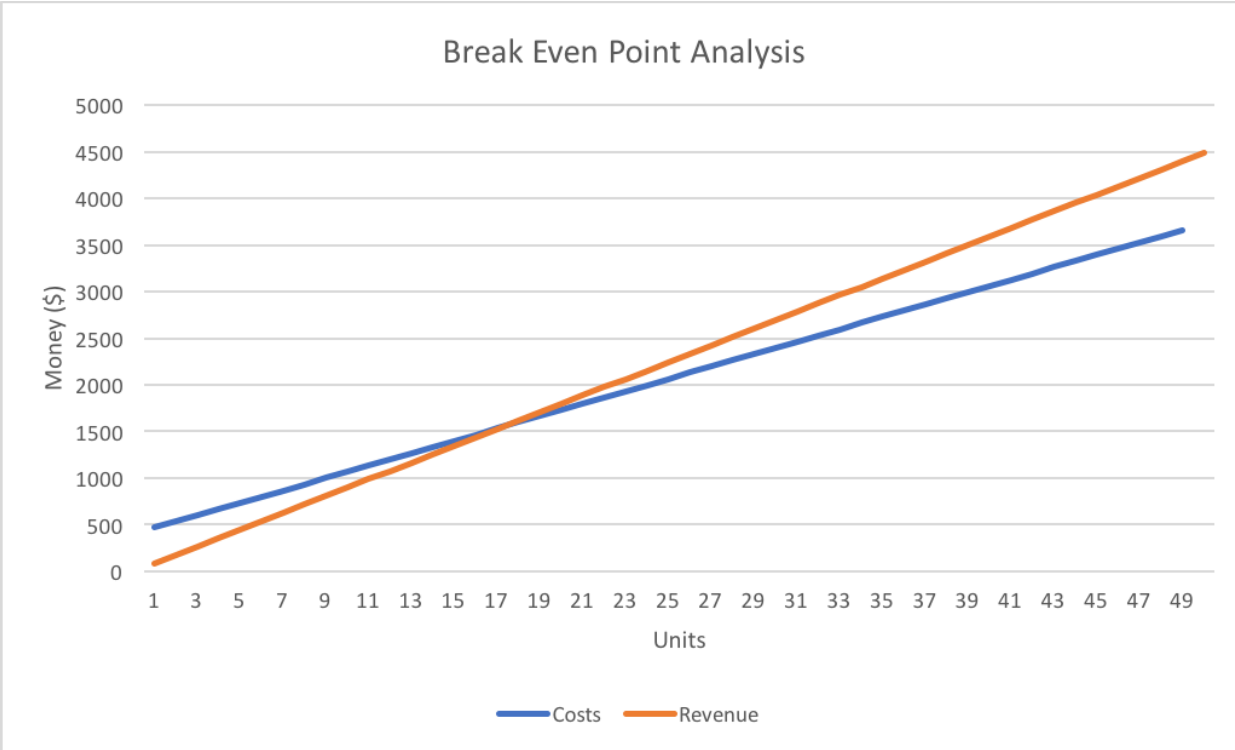


Figure 8: Break Even Point Analysis

Our product may be comparably priced to the Mann Lake HD540 Smoker, but it has operating costs associated with it that a traditional smoker does not. A traditional biomass smoker can be filled with nearly any biomass, which can be foraged on a bee colony farm. Our vapourizer based device will consume coils and e liquid on a periodic basis. Assuming that our device will consume one set of coils and 60mL of e liquid per month, it will cost the end user approximately $16 per set of coils per the bill of materials and $1 worth of propylene glycol, based on online pricing (Amazon, 2019a).

8.0 Conclusions and Recommendations

According to the Target Specification Table in section 7.4, our design met many of the target specifications except for a select few. Firstly, we satisfied the start up time target of our prototype, it was well below 5 seconds, approximately 2 seconds between actuation of the button and emission of vapour. It is also quite easy to use, requiring only actuation of one button for use. Vapour production was more than sufficient, as both of our clients were impressed with the volumetric mass flow of the device. The first of our shortcomings was that we were unable to to create a stable and safe wiring system for the internal components, given our knowledge and ability with circuit design. Also, the ergonomics of our prototype could be improved upon by increasing the exterior grip for one handed use. Given that our prototype did not meet every target specification, our team believes that this project should be continued and further developed. We laid the groundwork and our prototype proved that it is possible to produce enough vapour to sedate bees and that the atomizer and fan combination work well together, allowing for near instantaneous emission of sedating vapour. The overall design concept works albeit with some errors and hiccups in the process.

Furthermore, there is still testing to be done regarding which gassing fluid most effectively sedates the bees. We were not able to properly test our proof of concept on a bee hive due to time constraints of this project in relation to the bee season. Our suggestion would be to use a mixture of propylene glycol and liquid smoke to create an effective gassing fluid, however we cannot say with certainty that this will be the best solution.

The market for this device is large enough to constituent monetary investment to develop a more sophisticated version of our proof of concept and become a profitable venture. The estimated per unit prototype cost is $66.50 CAD, using off the shelf components and purchasing a hobbyist 3D printer and printing the shell in house. This cost could be drastically lowered using large scale production methods employed in modern day factories.

We do not think that our design is ready for production as it currently is. The design requires more work to overcome the obstacles that our team has failed to overcome due to internal constraints. Such obstacles include: incorporating a charge module, finding and sourcing a button that can withstand greater than 28A, developing a sleeve for added grip and waterproofing the seams between shell pieces. The shell may have to be remodelled to accommodate the design alterations. The scope of our recommendations are large enough to constitute a final engineering design project. With adequate time management skills and guidance, a design team with a timeline of two semesters should be able to complete these recommendations.

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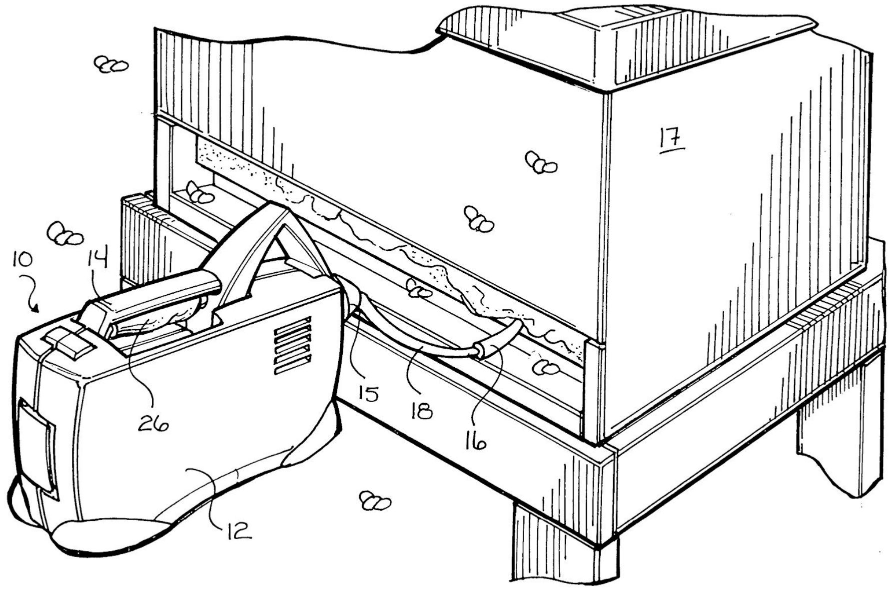
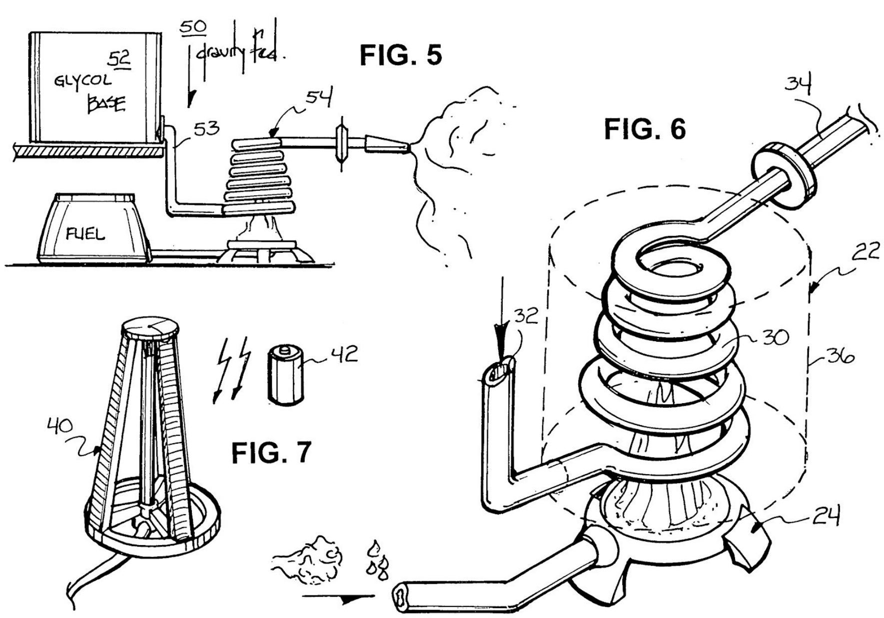
Appendix

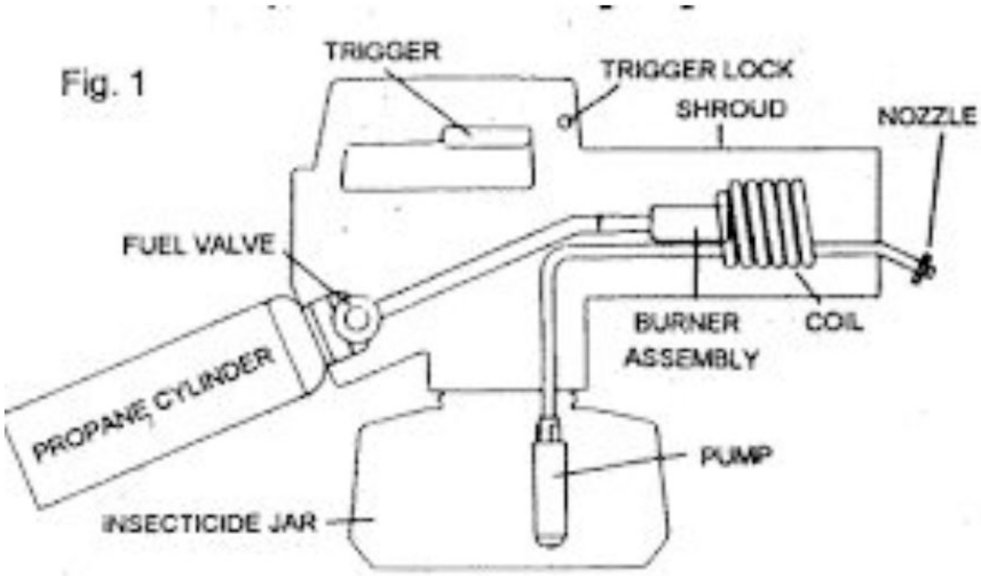


Younger, P. (2002). Portable vapour bee smoker.

Figure 9.1. Drawing depicting the Portable vapour bee smoker in use.



Younger, P. (2002). Portable vapor bee smoker.
Figure 9.2. Drawings giving detail to the internal components of the Portable bee smoker.



Scintex Australia. (2018). Burgess Propane Thermal Insect Fogger.
Figure 10. Drawing giving detail to the components of the Propane Thermal Insect Fogger.

Properties*	**ABS**	**PLA**
Tensile Strength**	27 MPa	37 MPa
Elongation	3.5 - 50%	6%
Flexural Modulus	2.1 - 7.6 GPa	4 GPa
Density	1.0 - 1.4 g/cm^3	1.3 g/cm^3
Melting Point	N/A (amorphous)	173 °C
Biodegradable	No	Yes, under the correct conditions
Glass Transition Temperature	105 °C	60 °C
Spool Price* (1kg, 1.75mm, black)**	$USD 21.99	$USD 22.99
Common Products	LEGO, electronic housings	Cups, plastic bags, cutlery

Figure 11. Properties of ABS and PLA Plastic
Giang, K. (n.d.). PLA vs. ABS: What's the difference?

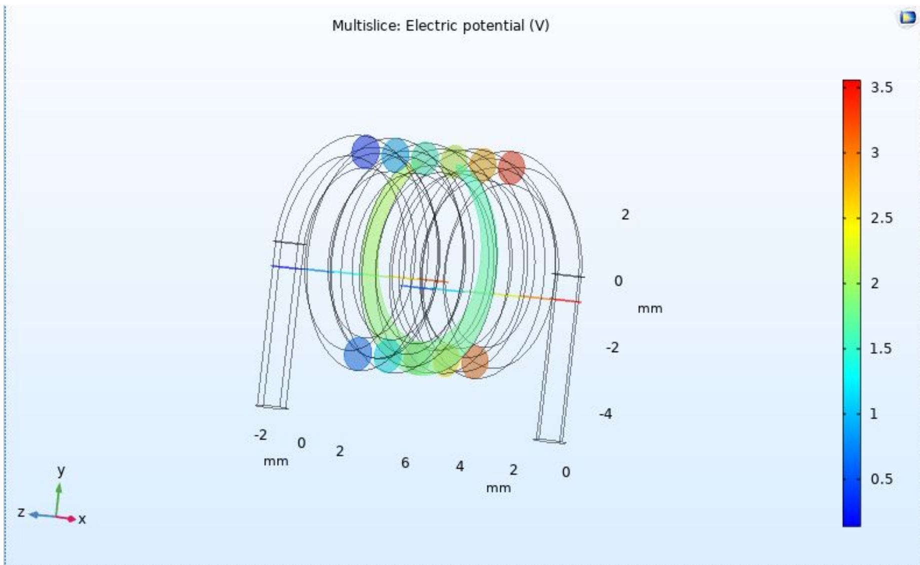


Figure 12.1 COMSOL Electrical Potential Variance Along the Coil

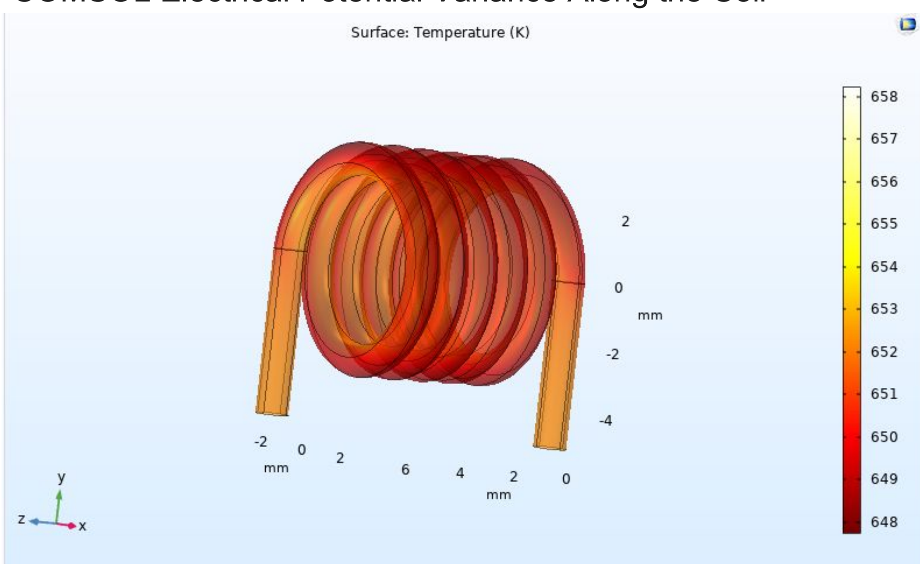


Figure 12.2 COMSOL Surface Temperature Variance Along the Coil

$$\rho C_p \mathbf{u} \cdot \nabla T = \nabla \cdot (k \nabla T) + Q_e$$
$$Q_e = \mathbf{J} \cdot \mathbf{E}$$

$$\rho C_p \mathbf{u} \cdot \nabla T2 + \nabla \cdot \mathbf{q} = Q + Q_{ted}$$
$$\mathbf{q} = -k \nabla T2$$

$$\nabla \cdot \mathbf{J} = Q_{j,v}$$
$$\mathbf{J} = \sigma \mathbf{E} + \mathbf{J}_e$$
$$\mathbf{E} = -\nabla V$$

Figure 12.3 COMSOL Heat Transfer Equations

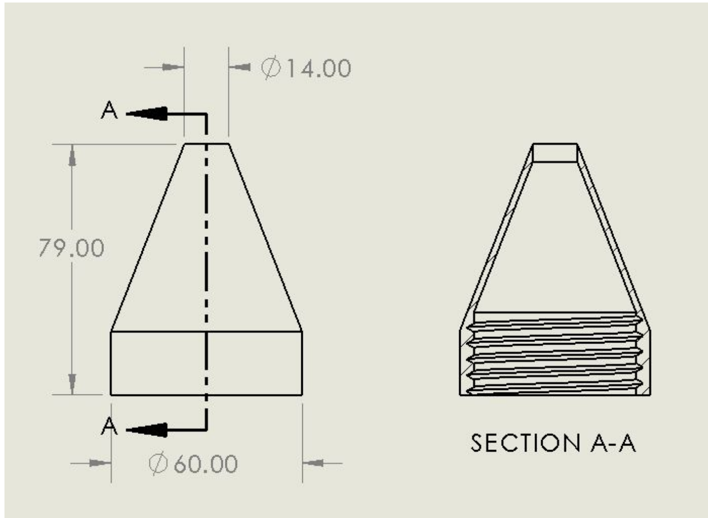


Figure 13.1 Top Cap with Threading

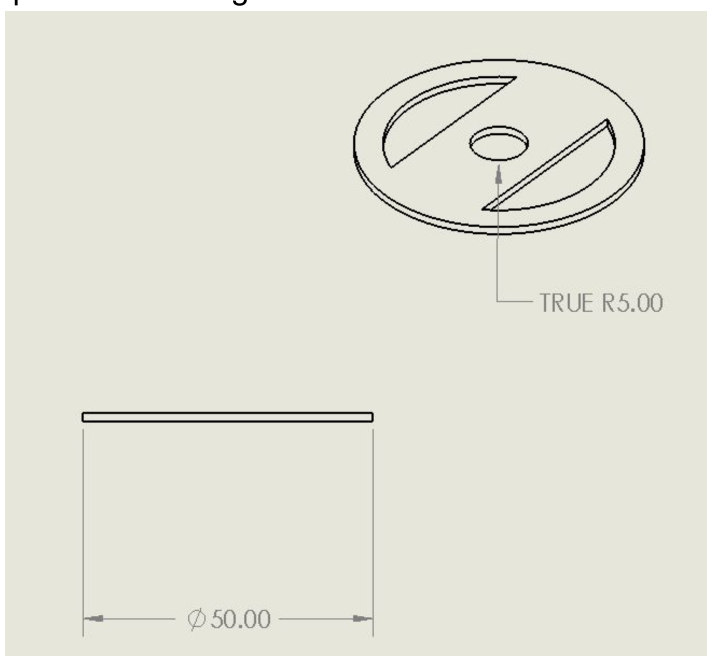


Figure 13.2 Atomizer Support Piece

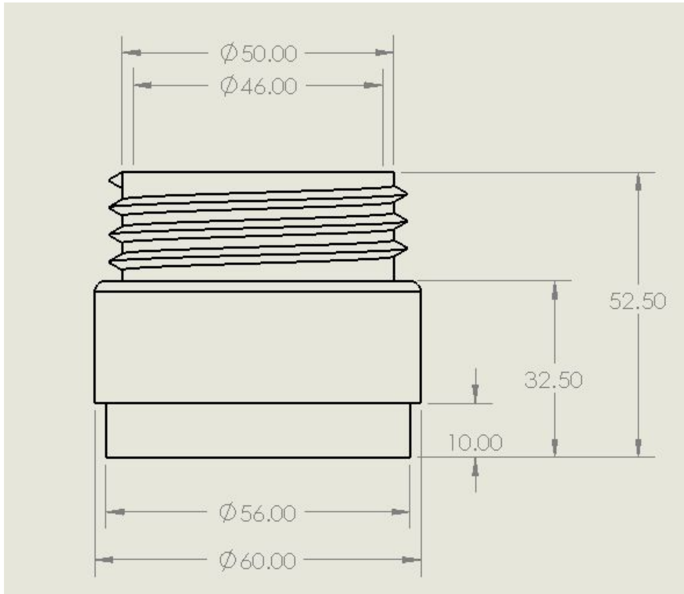


Figure 13.3 Midsection of Shell with Slip Joint and Threading

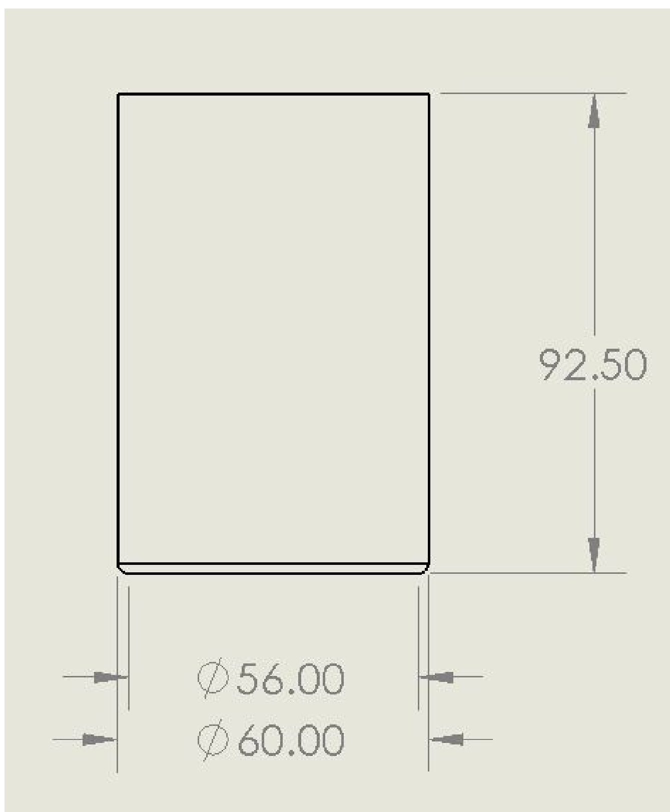


Figure 13.4 Bottom Section of Shell

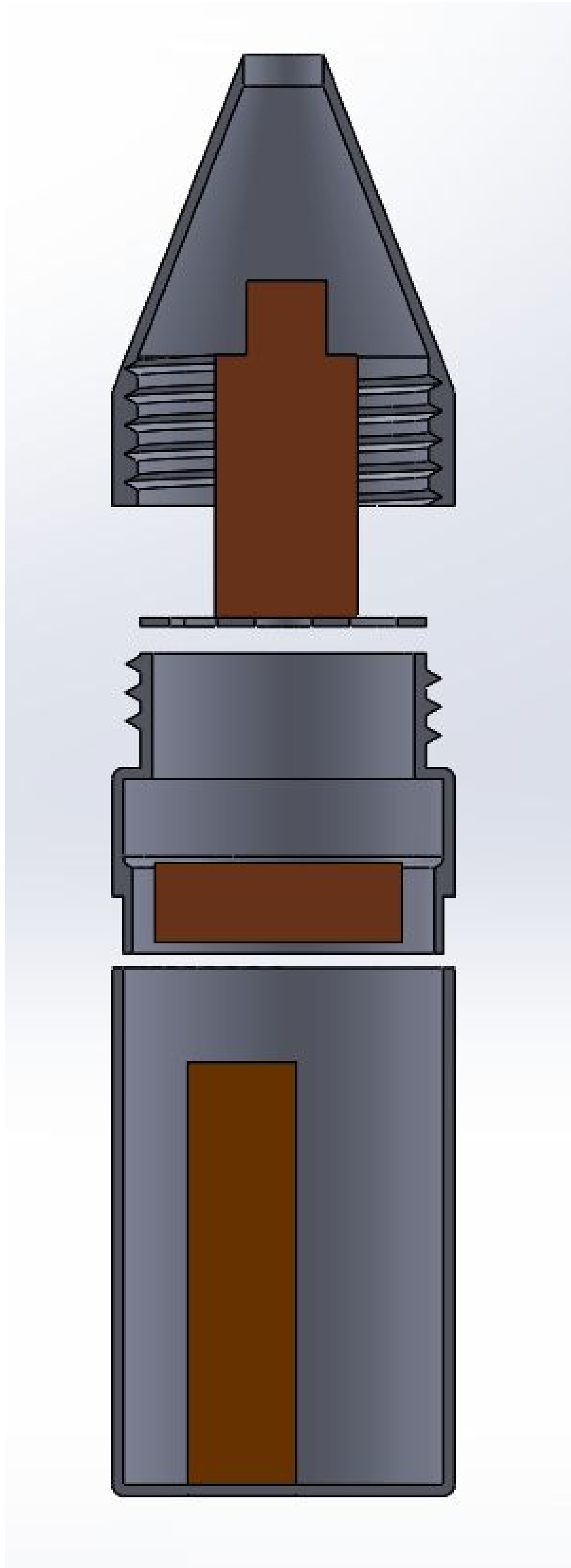


Figure 13.5

Table 7. Atomizer Specifications

Brand	Vaperz Cloud
Model	VCMT Clone
Style	Rebuildable Tank Atomizer (RTA)
Size	6ml
Body Material	Stainless steel
Tank Material	Glass
Approximate Dimensions	25mm x 63mm x 25mm
Approximate Weight	93g

Figure 14. Vaperz Cloud RTA Atomizer

Table 8. Battery Specifications

Brand	Sony Energy
Model	US18650VTC5A
Size	18650
Nominal Capacity	2600mAh

Nominal Voltage	3.7v
Maximum Voltage	4.2v
Maximum Continuous Discharge	25A
Approximate Dimensions	18.2mm x 65mm
Approximate Weight	47.8g

Figure 15. Sony VCT5A Batteries

Table 9. Fan Specifications

Brand	Elina Fan
Model	HDF4012L-05HB
Flow Rate	4.67 L/s
Current	240mA
Voltage	5v
Approximate Dimensions	40mm x 40mm x 14mm
Approximate Weight	20g

Figure 16. Elina 5v Fan

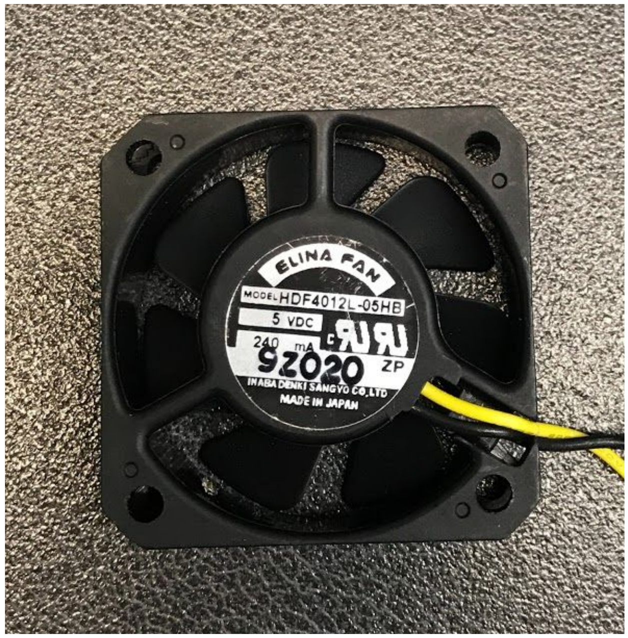


Figure 17. Example of vapour production capacity

VENTES

Magasin DDO
Accès Electronique DDO Inc.
43-B Boul. Brunswick
Dollard-des-Ormeaux, QC, H9B 1P7
(514) 421-2755
4/8/2019 @ 10:10:30 AM

Invoice Num : 3102736524
GST : 143995819
QST : 1037954397
Register # : 3102

Customer : VENTES A LA CAISSE
Address :
City : Québec, QC
Zip Code : G1N 2E3
Tel : (418) 691-3152
Cust ID : 00100001
Gen ID : 337868

270931 X
2 @ $1.99 = $3.98
(Support pour pile 2x '18650' avec fil)

Nb. of Items: 2

Sub Total $3.98
GST $0.20
QST $0.40
Total $4.58

Payment(s)

VISA $4.58
Authorization : 005699
Card # : ************3133
www.acceselectronique.ca
Toutes les ventes sont finales.

You have been served by
4731 - Kevin
Thank You

Figure 18.1 Cost of two 18650 battery holder

BMYVape
1831 Ste-Catherine Ouest
Montreal, QC H3H 1M2
514-825-8273

Caissier: KING RAGNAR
Facture:17939
02-18-2019 12:37

Produit	Qtё	Prix	Esc.	Total
VCMT SS CLONE	1	30.00	0.0%	30.00
TINO 0.15	1	15.00	0.0%	15.00
18650 VTC5 SONY	1	18.00	0.0%	18.00

Sous Total 63.00
TPS 3.15
Québec TVQ 6.29
Total 72.44
Debit 72.44

TPS/TVH 836656793RT0001
TVQ/TVP 1221836029TQ0001

Merci

VENTES

Magasin DDO
Accès Electronique DDO Inc.
43-B Boul. Brunswick
Dollard-des-Ormeaux, QC, H9B 1P7
(514) 421-2755
3/5/2019 @ 4:55:27 PM

Invoice Num : 3101729665
GST : 143995819
QST : 1087954397
Register # : 3101

Customer : VENTES A LA CAISSE
Address :
City : Québec, QC
Zip Code : G1N 2E3
Tel : (418) 691-3152
Cust ID : 00100001
Gen ID : 337868

51592 X
1 @ $2.99 = $2.99
(vent. 5vdc 40x40x10mm)

Nb. of Items: 1

Sub Total $2.99
GST $0.15
QST $0.30
Total $3.44

BMYVape
1831 Ste-Catherine Ouest
Montreal, QC H3H 1M2
514-825-8273

Caissier: baby cholo
Facture:18136
03-06-2019 11:23

Produit	Qtё	Prix	Esc	Total
COTTON BACON	1	8.00	0.0%	8.00

Sous Total 8.00
TPS 0.40
Québec TVQ 0.80
Total 9.20
Visa 9.20

TPS/TVH 836656793RT0001
TVQ/TVP 1221836029TQ0001

Merci

Figure 18.2 Cost of 5V DC fan (top right), Cotton wicking (bottom left) and 0.15 ohm coils (top left see "Tino 0.15")

Material	Quantity (in kg)	Emission Factor (e.g. kg	Total Cradle-to-Gate Emissions	Incoming Transport (in km)	Transport Emissions (per kg*km)	Total Emissions
Stainless steel	0.075	5	0.375			0.375
ABS plastic	0.126	4	0.504			0.504
Glass	0.017	0.7	0.0119			0.0119
Lithium ion batteries	0.096	11	1.056			1.056
Cotton	0.0005	2.7	0.00135			0.00135
Copper Alloy	0.005	3.7	0.0185			**1.94825**
			1.96675			

Figure 19.1 LinkCycle LCA Cradle to Gate Emissions

(R) = Recycled Material	Quantity (in kg)	Emission Factor (e.g. kg	Total End-of-Life Emissions	Outgoing Transport (in km)	Transport Emissions (per kg*km)	Total Emissions
Stainless steel (R)	0.075	0.73	0.05475			0.05475
ABS plastic (R)	0.126	3.1	0.3906			0.3906
Glass (R)	0.017	0.385	0.006545			0.006545
Lithium ion batteries	0.096	11	1.056			1.056
Cotton	0.0005	2.7	0.00135			0.00135
Copper (R)	0.005	0.83	0.00415			
			1.513395			**1.509245**

Figure 19.2 LinkCycle LCA End of Life Emissions

Assumptions (i.e. Operating 6 hours per day, for 5 years)			Electricity usage (in kWh	Emission Factor (e.g.	Total Emissions
Charging the batteries twice per week			1.61346	0.02	0.0322692
for the entire beekeeping season					**0.0322692**
(April to November), for 3 years					

Figure 19.3 LinkCycle LCA Use Phase Emissions