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REQUIREMENT FOR THE DEGREE OF
BACHELOR OF SCIENCE
IN
MECHANICAL ENGINEERING

Solar Powered Steam Engine

25% of Final Report

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Ethics Statement and Signatures

The work submitted in this B.S. thesis is solely prepared by a team consisting of Alejandro Forero, Charbel Saghira, and Victor Berrueta and it is original. Excerpts from others' work have been clearly identified, their work acknowledged within the text and listed in the list of references. All of the engineering drawings, computer programs, formulations, design work, prototype development and testing reported in this document are also original and prepared by the same team of students.

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Team Leader	Team Member	Team Member

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Abstract

Thermal energy is the least utilized source of renewable energy in the world, accounting for two-tenths of 1 percent of the total energy consumed in the United States. As more people are starting to realize the great potential involved in harvesting the energy from the sun, solar technology has been advancing rapidly in recent years. As fossil fuels prices keep increasing and harmful emissions keep endangering our environment, green technology is the only way to stir away from an inevitable environmental disaster. The system proposed in this report will convert thermal energy into mechanical by means of the Rankine cycle. The Rankine cycle is responsible for generating 85% of the electricity in the world either by biomass, coal, solar and nuclear power plants. Not only will this project not pollute the environment, but it will also help by showing people that there are better, cleaner and more efficient ways to generate power. The main components which will require the most attention will be the solar reflector, and the actual steam engine.

1. Introduction

1.1 Problem Statement

Current methods to produce energy for the broad masses of the world are dangerously dependent on non-renewable fossil fuels. Governments around the world have started to recognize that Fossil fuels will not last forever and a growing world population cannot depend on them for much longer. In addition to the growing scarcity of fossil fuels, often times the methods to collect and produce energy from these fuels is proven to be harmful to the environment and have negative side effects to humanity;   power generation is a leading cause of air pollution and the single largest source of U.S. global warming emissions.

Despite the fact that electricity was made useful and progressively vital for humanity centuries ago, there is still approximately 1.3 billion or almost 20% of the world's population without access to electricity [2]. Many under-developed countries around the world receive vast amounts of sunlight; the most prominent solar energy technology today is photovoltaic which has high cost-efficiency margins for installation and attainability making it difficult for under-developed countries to adopt it. An alternative to harvest the energy of the sun is concentrated solar power (CSP), but current processes that utilize CSP also have a high cost per energy produced. An economic CSP system could greatly improve the lives for those who do not have access to electricity or decide to live off the grid.

1.2 Motivation

Efforts to find "green" alternative ways to produce energy and renewable fuels have increased significantly in the last decade; there are multiple efforts from governments to support and invest by providing incentives and tax breaks for renewable clean energy. Besides the advantages provided by the U.S. government an affordable CSP system is beneficial worldwide by providing vital power for different necessities for those who don't have access to electricity. Another advantage and reason to develop a CSP is that unlike photovoltaic technology it can not only produce electric power but thermal power as well, this thermal power can be used for cooking, water distillation, thermal refrigeration cycles, and other refinement applications that the creation of steam provides.

1.3Literature Survey

Increasing solar power density by concentrating solar rays is nothing new; it has been theorized and researched for thousands of years, the first documented example of this comes from the story of Greek scientist Archimedes (287-212 B.C.) burning down invading Roman ships in 212 B.C.

Figure 1: Archimedes Solar Reflector

Later in history solar concentrators began being used as furnaces in chemical experiments, mainly because of the high temperatures they could obtain without the use of any form of fuel besides sunlight. More involved application started when August Mouchot used a parabolic solar concentrator to generate low-pressure steam to operate steam engines between 1864 and 1878. Abel Pifre developed a solar engine to operate an printing press in 1878 in Paris [4]. This sparked more research into the technology which was considered too expensive to be developed completely.

In the twentieth century many projects utilizing solar concentration were developed, ranging from water distillation to steam power generator. In 19 12 Shuman and Boys developed a 50kW solar pump to pump irrigation water from the Nile river, A 1200m^2 reflector field was used to provide the needed steam. In 1920J.A. Harrington created a steam engine to pump water into a tank that acted as a source of power for a turbine being used inside a mine [3]. After WWII the discovery of cheap fossil fuels overshadowed solar power research and became the new standard for energy usage.

Interest in solar power came back into the spotlight in the 70's and 80's when a shortage in gas and oil had occurred. In 1977 about one hundred 7m parabolic dishes were used to heat silicon-based fluid for a steam Rankine cycle. More modern examples include a system developed by the Department of Energy's Dish Engine Critical Components (DECC). The system consisted of an 89m^2 dish that collected the thermal energy required to run a sterling engine which would turn that thermal power to electricity [4].

2. Project Formulation

2.1 Project Objectives

The main objectives of this project is to provide clean source of power with zero emissions by creating rotational energy from a steam engine that can be transformed into electricity via a generator. A secondary use for the steam or heated water would be to implement into a household as a water heater to save energy and money. A more specific objective is to design and construct a solar collector in order to produce steam or hot water, the collector needs to be efficient enough to conserve heat while the sun is overshadowed by clouds. The design and assembly of a steam or Stirling engine to run with the output steam of the solar collector. Another objective, if time permits, is to be able to close the system with a condenser and pump that will recycle the exhaust steam from the engine back into the solar collector.

3. Design Alternatives

3.1 Alternative Design of Engine

For the alternative design of the engine we would be transforming a gasoline engine into a steam engine. The best alternative for this design is a gasoline engine of two-stroke cycle that can be easily obtained.

We decided to choose the engine of a weed eater because this type of engine has a spark plug facing directly the piston. This is needed in order for a better distribution of the steam on the piston. The only things you need from the weed eater's engine are the block, the piston, and the crank. The conversion is done by removing the spark plug from the block, and assembling a type of connection between the spark plug hole and the steam. This connection is composed of an adaptor, a check valve, and copper rod, which is attached to the check valve in order to let the steam in when the piston reaches its maximum height. The picture below was obtained from Animated Engines webpage just to show an example of how it would work.

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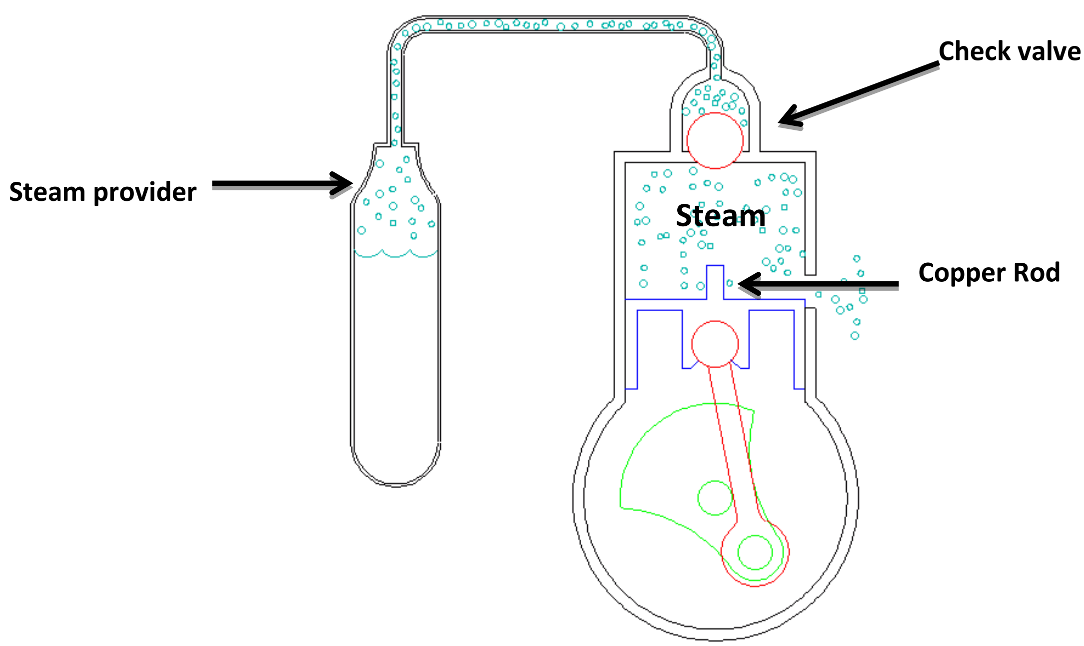


Figure 2: Steam Engine Representation

3.2 Alternative Design of Solar Reflector

For the alternative design of the Solar Reflectors, we would be using a parabolic trough collector, long, U-curved mirror. This system is composed of the reflectors, a receiver tube, and a metal support structure.

The reflectors (which would be made of would be a glass mirror with aluminum coat) focus the solar beams into an absorber pipe, which is located right above the middle of the reflectors, which has a medium to absorb the heat running through it (Wang, 2008). The sun's rays would travel in a linear axis from left to right. The sun heats up this medium, and this is directed to the water in a boiler heat exchanger, producing the steam to be injected into engine. The picture below is a representation by Professor Yiting Wang of how it would look like.

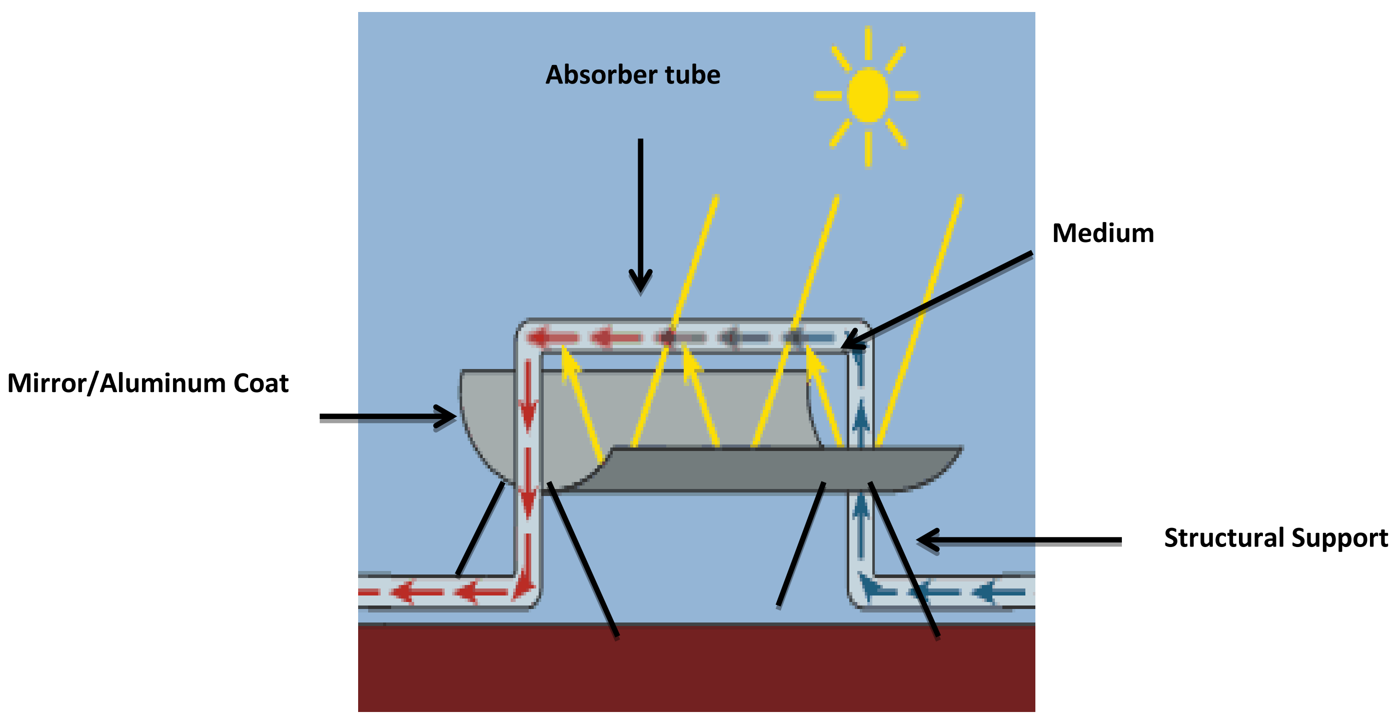


Figure 3: U- Shape Reflector

3.3 Alternative Design of Solar Collector

Another alternative design that will be use is a conical shape heat absorber made of copper. Copper is a good absorber of heat and solar radiation; therefore it is a good alternative because it would not have to be rotated in a specific angle. It would always absorb the heat regardless the position of the device. Tubes, also made of copper, will go around the entire inside of the conic, which will conduct the water. This device will have a water pump connected at the end of the tubes, and will also have a flow rate regulator. The theory is that the sun will heat the conic and tubes enough to transform water to steam, directly injected to the engine.

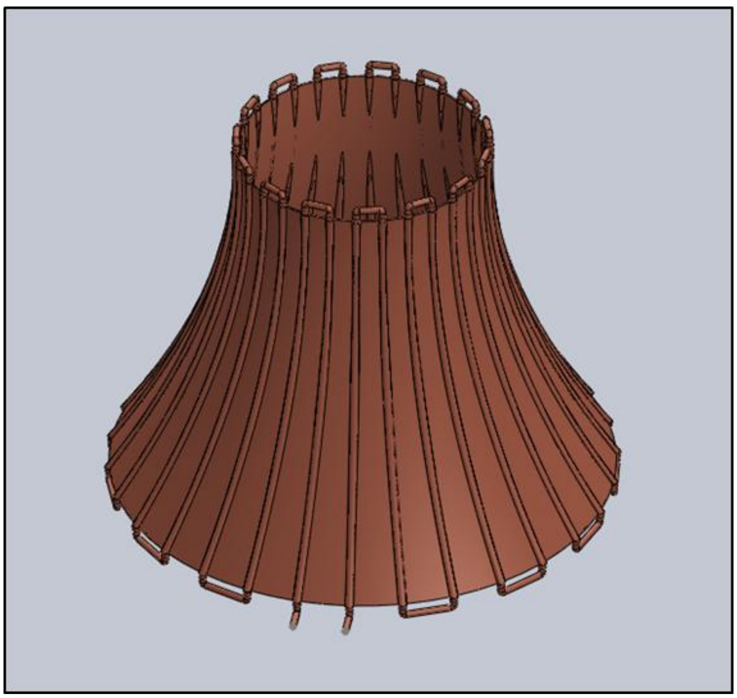
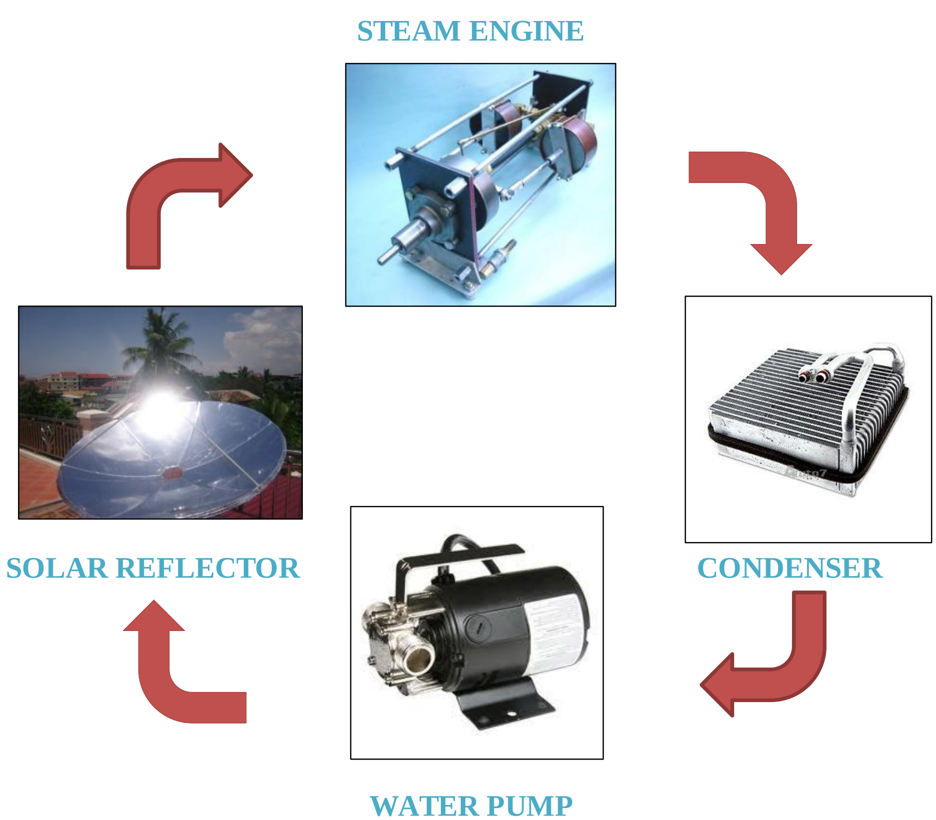


Figure 4 Solar Collector without cover

4. Proposed Design

The system proposed in this report will utilize a solar reflector in order to concentrate the solar beams from the sun into a small boiler where refrigerant 134a will boil producing steam. The reason for choosing refrigerant 134a over water is the lower boiling point therefore requiring less energy for the vaporization state. The created steam will then flow into an engine where mechanical energy will be generated. The steam will then exit the engine and flow into a condenser where it will be converted back into liquid state and be pumped back into the solar reflector.



4.1 Proposed Design of Solar Collector

For the proposed design of the solar collector a conical shape heat absorber made of copper will be used with a cover made of glass. Copper will be used because it is a good material to absorb heat and solar radiation. Tubes, also made of copper, will go around the entire inside of the conic, which will conduct the water. This device will have a water pump connected at the end of the tubes, and will also have a flow rate regulator. The water will be converted into steam, and afterwards directly injected to the engine. The system will have a cover made of glass with the purpose of retaining and keeping solar radiation trapped inside for more efficiency. Glass allows short wave radiations to go through, but it does not allow long waves to leave, trapping the re-radiated waves inside.

The advantage if using this type of system is that no matter where is positioned with respects to the sun, the copper will always absorb heat. Likewise, have a glass cover will not allow weather and other conditions to interfere with the process.

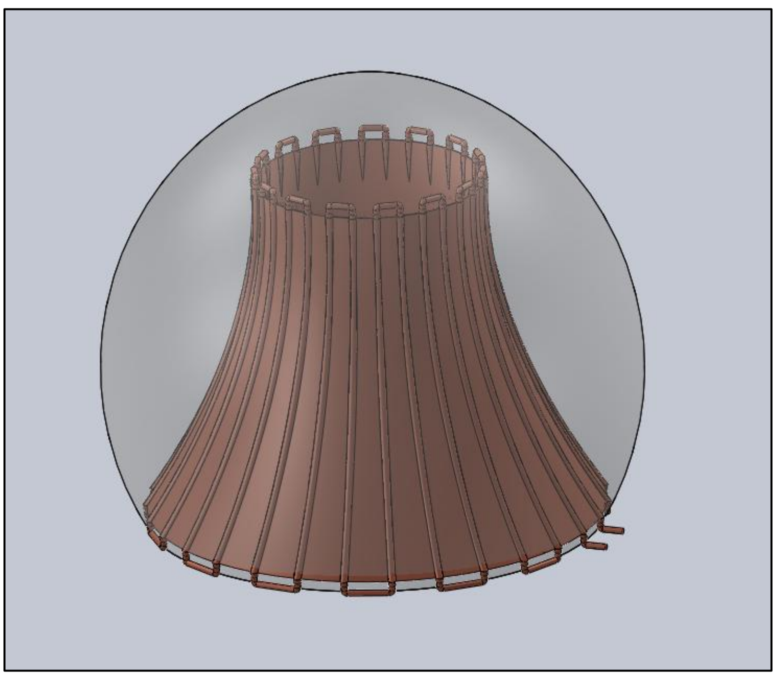


Figure 4: Parabolic Solar Collector

5. Project Management

5.1 Overview

The project described in this report has two major components which will required the most attention in order to successfully achieve positive results. Since each team member has a different set of skills, the responsibilities will be distributed accordingly to make the best out of the situation.

5.2 Timeline

The timeline for the project topics shown below is the expected schedule starting in March and ending in December with the completion of the project. The work distribution timeline shows how work is being distributed amongst the team member according to their strengths. The project is expected to begin prototype construction in the summer months and be finished by early December.

Table 1: Timeline of Objectives

2014 Timeline										
Topic	March	April	May	June	July	August	September	October	November	December
Project Formulation										
Literature Survey										
Project Constrains										
Proposed Design										
Design and Analysis										
CAD Model										
Part List										
Cost Analysis										
Prototype Construction										
Prototype Test										
Final Report										
Final Presentation										

5.3 Team members responsibilities

This is a table showing the responsibilities of each team member. Please note that all reports and presentations were put together as a group effort, distributing the work amongst all team members equally. This project has been a cooperative effort of the three mentioned students and Dr. Andres Tremante as team advisor.

Table 2: Team Members Responsible

Team member	Tasks and responsibilities breakdown
Alejandro Forero	Research and design of system
	Solidworks modeling and system simulations
	System assembly and testing
Charbel Saghira	Cost analysis of system components
	Testing and manufacturing of prototype
	Material analysis for system components
Victor Berrueta	Solar Collector research and Modeling
	System assembly and testing
	Structural analysis

6. Analytical Analysis

The proposed design will need to be analyzed before construction of a prototype takes place in order to make sure that the desired results will be accomplished. Most of the formulas used in order to analyze the system can be obtained from Heat Transfer book, and also require knowledge of Transport Phenomena. The goal is to achieve at least 10 to 15 pounds of steam pressure, in order to achieve this, the minimum required area will need to be calculated and the volumetric flow rate of the fluid, in this case being water or refrigerant 134a. The solar collector will have a parabolic shape, with the sun being located at the focus. Since the collector will also be concealed by a glass enclosure in order to generate a greenhouse effect and prevent the temperature from dropping, the shape and area of that glass surface will also need to be calculated. Some of the formulas required to solve this are the following:

Mass Flow Rate	$\dot{m} = \rho \mathcal{V} A_c$	(kg/s)
Conduction	$\dot{Q}_{\text{cond}} = -kA \dfrac{dT}{dx}$	(W)
Radiation	$\dot{Q}_{\text{rad}} = \varepsilon \sigma A_s (T_s^4 - T_{\text{surr}}^4)$	(W)
Convection	$\dot{Q}_{\text{conv}} = hA_s (T_s - T_\infty)$	(W)
Heat Transfer Rate	$\dot{Q} = \dot{m}\Delta h = \dot{m} C_p \Delta T$	(kJ/s)
Parabolic focus	$Y^2 = 4ax$	

7. Major Components

7.1 Solar Collector

The Solar collector is the most important component for this project since the ability to generate steam is determined by how efficient the collector functions. There is a wide variety of solar collectors that could match the proposed system, so it was important selecting a certain type according to the minimum required specifications. After much consideration and advice from Dr. Tremante, we decided to build our own solar collector. In order to maximize the area being directly hit by sunlight, we decided to make the solar collector parabolic.

7.2 Steam Engine

The steam engine selected is expected to run on approximately 10 to 15 psi of steam pressure, even though it will actually function with as little as 2 psi of pressure. The design consists of few moving parts therefore decreasing the chances of running into problems later on. The Engine's configuration can be modified in order to maximize speed or power. As of right now, the steam engine selected for the project is the Green Steam Engine mentioned earlier, but there is also a chance that a gasoline engine converted to run with steam may also be used.

8. Structural Design

The solar collector needs to be designed in such a way that it will not fail due to the internal pressure generated by the system or the outside weather conditions. Materials need to be chosen wisely depending on the applications, for example in order to maximize heat absorption the side tubes and walls need to be made out of copper, as it is an easy material to mold and cut to the desired dimensions. For the outside cover of the system, glass would be the recommended material since it would capture the most heat generating the desired greenhouse effect, but it would also be the most fragile, making plastic a better and cheaper choice.

The steam engine will be made mostly from aluminum and brass, since reliability is an important factor being considered in the design. The safety of the system is just as important as the efficiency expected of it, since high temperatures and pressure will be constantly present during testing and troubleshooting, pressure gauges will also be installed at key places, in order to easily determine if the system is working properly or changes need to be made.

9. Cost Analysis

The Solar collector is composed of four different parts that include:

- Copper Tube
- Sheet of Copper
- Copper Return Bend
- Water Pump
- Shut Off Valves
- Glass

Table Show the cost and of the components we are going to use in our project.

Some price may change due to the size of our project but it will guide you to have an idea of the cost of our project.

Table 3: Cost Analysis of materials

Components	Description	Cost
Copper Tube	1/4" Diameter 50 ft. copper coil	$43.34
Sheet of Copper	24" x 24"x 0.0625"	$145.97
Copper Return Bend	Connector 25 units (Box)	$49.75
Water Pump	Pacific Hydrostar 200GPH	$34.99
Shut Off Valves	1/2" Quarter Turn	$6.37
Glass Cover	24" x 24" Clear Glass sheet	$59.97
	Total	$340.39

Table 4: Projected hours of each Member

Responsibilities	Alejandro Forero	Victor Berrueta	Charbel Saghira	Human hours Spent
Design Alternatives	5	5	10	20
Proposed Design	10	10	5	25
Analytical Analysis	10	5	10	25
SolidWorks Modeling	10	5	10	25
Prototype System Description	5	5	5	15
Plan For Testing	5	5	5	15
Report Preparation	10	10	10	30
			Total Hours	155

10. Prototype System Description

The system will ideally consist of four components, solar collector, small steam engine, condenser, and water pump. Each of this components have a vital role in the ideally closed system being designed, however, the heart of the project is the solar collector. All other components are designed around the capability of the solar collector to produce steam using thermal energy from the sun. The minimum requirement to produce usable energy from the steam is to produce 15 to 25 psi of pressure. The dimension of the collector are still being calculated for the purpose of creating the minimum steam pressure while keeping it as small and compact as possible. After the collector creates the steam required to free wheel the small steam engine the exhaust steam will then be guided to a condenser where it will be turned back into water and pumped back into the solar collector to be reheated. The system's efficiency will depend on how efficiently the solar collector can turn the volume of water flowing through it to steam and steam engine's capability to turn relatively low pressure of steam into torsional energy.

10.1 Prototype Cost Analysis

The cost analysis for the prototype mechanism is composed:

- Components Cost
- Labor

Prototype Cost = Components Cost + Labor Cost

The prototype cost analysis will include the labor and the components needed it to build this project. This is a very uneven estimation and we expect that the cost go up as we continue developing this project. As a group we decided to divide the work in equal amount so each member will have the same amount of work throughout the project. Also, we are trying to find used it materials in order to reduce the cost. Moreover, the cost of the project depends in the size, performance and material to be use.

The major Components for this Project are:

10.1.1 Copper Tube

Figure 5 Copper Tubing

TABLE 1. Copper Tube: Types, Standards, Applications, Tempers, Lengths

Tube Type	Color Code	Standard	Application[1]	Commercially Available Lengths[2]		
				Nominal or Standard Sizes	**Drawn**	**Annealed**
TYPE K	Green	ASTM B88[3]	Domestic Water Service and Distribution, Fire Protection, Solar, Fuel/Fuel Oil, HVAC, Snow Melting, Compressed Air, Natural Gas, Liquified Petroleum (LP) Gas, Vacuum	**STRAIGHT LENGTHS:**		
				1/4-inch to 8-inch	20 ft	20 ft
				10-inch	18 ft	18 ft
				12-inch	12 ft	12 ft
				COILS:		
				1/4-inch to 1-inch	—	60 ft
					—	100 ft
				1 1/4 inch and 1 1/2-inch	—	60 ft
				2-inch	—	40 ft
					—	45 ft
TYPE L	Blue	ASTM B88	Domestic Water Service and Distribution, Fire Protection, Solar, Fuel/Fuel Oil, Natural Gas, Liquified Petroleum (LP) Gas, HVAC, Snow Melting, Compressed Air, Vacuum	**STRAIGHT LENGTHS:**		
				1/4-inch to 10-inch	20 ft	20 ft
				12-inch	18 ft	18 ft
				COILS:		
				1/4-inch to 1-inch	—	60 ft
					—	100 ft
				1 1/4 inch and 1 1/2-inch	—	60 ft
				2-inch	—	40 ft
					—	45 ft
TYPE M	Red	ASTM B88	Domestic Water Service and Distribution, Fire Protection, Solar, Fuel/Fuel Oil, HVAC, Snow Melting, Vacuum	**STRAIGHT LENGTHS:**		
				1/4-inch to 12-inch	20 ft	N/A
DWV	Yellow	ASTM B306	Drain, Waste, Vent, HVAC, Solar	**STRAIGHT LENGTHS:**		
				1 1/4-inch to 8-inch	20 ft	N/A
ACR	Blue	ASTM B280	Air Conditioning, Refrigeration, Natural Gas, Liquified Petroleum (LP) Gas, Compressed Air	**STRAIGHT LENGTHS:**		
				3/8-inch to 4 1/8-inch	20 ft	[4]
				COILS:		
				1/8-inch to 1 5/8-inch	—	50 ft
OXY, MED, OXY/MED, OXY/ACR, ACR/MED	(K)Green (L)Blue	ASTM B819	Medical Gas Compressed Medical Air, Vacuum	**STRAIGHT LENGTHS:**		
				1/4-inch to 8-inch	20 ft	N/A

[1] There are many other copper and copper alloy tubes and pipes available for specialized applications. For information on these products, contact the Copper Development Association Inc.

[2] Individual manufacturers may have commercially available lengths in addition to those shown in this table.

[3] Tube made to other ASTM standards is also intended for plumbing applications, although ASTM B88 is by far the most widely used. ASTM Standard Classification B 698 lists six plumbing tube standards including B 88.

[4] Available as special order only.

20

Figure 6 Copper Tubes Types, Standards, Applications, Tempers and Lengths

10.1.2 Copper return bend

Figure 7 Copper return connector

Return Bend Specification:

- Copper
- ¼ inch Diameter
- 180° Return Bend

10.1.3 Copper Sheet

Figure 8 Cooper sheet

Copper Sheet Specification:

- 24'' x 24'' x 0.0625"
- Ductile Metal
- Good Conductor of heat

- Durability and Resistance to Corrosion

10.1.4 Shut off Valve:

Figure 9 Fluid Valve

Description | Specifications | Reviews | Community Q&A

Type	Valve
Configuration	Straight
Quarter Turn	Yes
Material	Brass
Finish	Rough brass
Fits What Pipe Material	Iron pipe
Inlet Dimensions	1/2-in

Inlet Thread Type	FIP
Primary Outlet Dimensions	1/2-in
Primary Outlet(s) Thread Type	Female iron pipe thread
Secondary Outlet Dimensions	N/A
Secondary Outlet(s) Thread Type	N/A
CA and VT Low-Lead Standards Compliant	Yes
Code Approvals	Yes

10.1.5 Water Pump:

Figure 10 Water pump

Description

PACIFICHYDROSTAR.

Compact and lightweight, this self-priming 12V pump is ideal for clearing bilges and for other marine applications, as well as utility pumping around your home. Pumps water at up to200 GPH (gallons per hour). Clips onto 12V battery terminals.

- Stainless steel pump housing for use in salt or fresh water
- Maximum flow: 200 GPH (gallons per hour)
- Total head lift: 23 ft.
- Dual threaded inlet and outlet:

Not for use with fuel or flammable liquids.

Specifications

Name	12 Volt Marine Utility Pump
SKU	9576
Brand	Pacific Hydrostar
Amperage (amps)	5
DC Volts	12
Head lift (ft.)	23 ft.
Maximum pressure (PSI)	10 PSI
Wattage (watts)	50
Outlet fitting size	3/8 in-18 NPT female and 3/4 in-11 NPT male
Product Length	5-3/4 in.
Product Width	2-1/2 in.
Shipping Weight	3.73 lb.
Warranty	90 Day

10.1.6 Glass Cover

Figure 11 Cover for Solar collector

Specifications:

- Good Glazing Materials
- High Transmission
- Low Iron Tempered Glass
- High Temperature Capability
- Reduce Heat Loss

10.2 Prototype Tests

Plans for testing will be concentrated at the solar collector and steam engine. For the solar collector will be tested for absorption of the irradiation that is received from the sun, if temperature does not reach the value needed to produce steam, the collector will be enclosed with a plastic clear cover to eliminate the loss of heat from the air's convection. Different angels of parabolic bends will also be tested to find the ideal curve to have the most surface area of the collector exposed to the sun. The flow rate of the water flowing through the copper tubes will be tested to find the perfect balance between speed of the fluid and the rate at which the water evaporates. This test will carry over to the steam engine to find the ideal flow rate of fluid to have the largest steam pressure possible to go to the steam engine. Different angles of inclination for the solar collector will also be tested to see if having more surface area exposed at different times of the day yields better results. Different exit valves will be implemented into the design of the reflector; these will be tested to see if having the fluid exit before flowing through the part of the reflector that is not getting hit by the sun's rays yields better results in terms of the pressure of steam being created. Different pipe lengths connecting the different components of the system will also be tested to find the best way to have the water flow run through each component. The ideal diameters of the copper wires where the water will be heated will be calculated before construction and they will be field tested to see if they correlate with the mathematical calculations.

11. Conclusion

In conclusion, as cheaper and more efficient ways to harvest thermal energy are invented, the dependency on fossil fuels will steadily decrease, creating an interest on major companies to implement green energy for their applications. This type of technology also affects areas of the world where electricity has yet to be introduced due to lack of government funding or infrastructure. Introducing solar energy to places where electricity is not available will allow for people to be independent of a power grid, therefore reducing the electricity generation through power plants. This project will demonstrate that smaller scale thermal energy can be achieved at a reasonable cost and efficiency. As technology advances, better and more efficient ways to harvest thermal energy will reduce the need for coal burning plants to be built and render existing ones obsolete.

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