# Engineering for Sustainability: A Solar coffee Machine (Solacoff)

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**ABSTRACT**
*Over the last 20 years, environmental issues have gained greater public recognition. The general public has become more aware that the consumption of manufactured products and marketing services, as well as the daily activities of our society, adversely affect supplies of natural resources and the quality of the environment. For these reasons, a range of "Design for Environment" tools are now emerging to assist and intensify the development and application of methods to identify and reduce the adverse environmental effects of these activities. In this paper, a typical case study of the design and manufacturing of a light, portable and energy efficient coffee machine (Solacoff) is presented. Different keys environmental issues such as "Design for energy conservation" and "Design for material and waste minimization" have so far been addressed with respect to public concerns and governments regulations.*

**Keywords:** Engineering, energy, materials, sustainability.

## 1. Introduction

The definition of Design for Environment (DFE), which at least initially was not clearly univocal, has evolved over the last decade [1]. It was presented in a reductive manner as a design approach directed at the reduction of industrial waste and the optimization of the use of materials. Ultimately, Design for Environment can be defined as a methodology directed at the systematic reduction or elimination of the environmental impacts implicated in the whole life cycle of a product, from the extraction of raw materials to disposal. Maintaining the necessary attention on the management of waste and resources, and integrating it in a system vision clearly inspired by the principles of Industrial Ecology, it can be understood more completely as a design process that must be considered for conserving and reusing the earth's scare resources [2]. Typically, in some ways, sustainable engineering may be thought of as the operational arm of industrial ecology: first use the methodologies of industrial ecology, such as life-cycle assessment, material flow accounting, or product and process matrix analysis, to determine relevant social and environmental considerations; then use sustainable engineering methods to integrate that knowledge into process, product, and infrastructure design and life-cycle management. But this deceptively simple formula, although it adequately describes a working conceptual relationship, oversimplifies the challenge to both industrial ecology and sustainable engineering.

Sustainable engineering tools that have emerged from these environmental pressures can be classified into two, somewhat overlapping groups [3]. These are analysis tools which are used to identify the environmental impact of a product throughout its life cycle and improvement tools to facilitate and assist designers to improve the environmental performance of their products.

## 2. Improvement tools

The key environmental issues, that improvement tools have so far been developed to address, include:

- Design for recovery and reuse including:
  Design for material recovery
  Design for component recovery
- Design for disassembly and simplicity
- Design for waste minimization including:
  Design for resource reduction
  Design for separatibility
  Design for waste recovery and reuse
  Design for waste incineration
- Design for chronic risk reduction
- Design for accident prevention
- Design for energy conservation
- Design for material conservation including:
  Design of multifunctional products
  Design for product longevity
  Design for closed-loop recycling
  Design for packaging recovery
  Design of reusable containers
  Develop leasing programs

Manufacturing firms, in a variety of industries, commonly practice these guidelines. While it is not comprehensive, it illustrates the range of practices that may be considered in DFE [4]. To be truly useful to a particular company and product team, these types of guidelines need to be converted from the general statements to more specific approaches that are applicable to the product in question. Typically, in the following case study we apply specific changes to the product design leading to the improvement of product environmental impact and consequently to the application of some DFE principles and guidelines [5].

## 3. Design and Manufacturing of a Solar Coffee Machine

This activity will be performed with solar energy input by using solar panels or a parabola device. We consider two types of solar panels:

- Electricity Production (Photovoltaic or PV Technology)
- Water Heating (Solar Thermal or Flat Plate Technology)

PV cells:

Photovoltaic (PV) cells utilize semiconductor technology to convert solar radiation directly into an electric current which can be used immediately or stored for future use. PV cells are often grouped in the form of “modules” to produce arrays [6].

**Heat measurement**

Heat capacity, usually denoted by a capital C, is a measurable physical quantity which characterizes the amount of heat required to change a body's temperature by a given amount [7]. In the International System of Units, heat capacity is expressed in units of joules per Kelvin.

From the formula: $Q=mc\Delta T$

The volume of water is 0.6L

C=4.18kJ/kg $^0$C; $\Delta$T= (72-22) =50; Q= 0.6*4.18*50 =125.4KJ=125400J
The resistance available: 5 ohms.
The battery delivers a voltage of 12V and a power of 28W
Then, the heat dissipated by the resistance is: $P = V^2/R = (12)^2 / 5 = 28$ W
So, the time required for the 0.6L to be heated is 125400(J)/28(J/s) = 4478s = 74.64min. or 1.25hours.
Since the result was unpredicted we proceeded with another method to verify our result.

**Alternative solution to heat the water**

The alternative solution consists of using a geometrical shape that concentrates the rays coming from the sun to a certain point called the focal point and heating the water directly, instead of converting this energy into electricity.
The efficiency of the thermal solar method can reach a value of 70% which is very high compared to 16% for the solar panel method.
By using the day light calculation device it can be verified that the energy gained from the light is between 500W/m$^2$ and 1000W/m$^2$. Depending on the area of our geometrical shape considered we will be able to calculate the amount of energy collected by our reflector.

**The power of the parabola**

The parabola is the best geometrical shape for the construction of our reflector and that is because of its particular feature that no other shape provides; the focal point.
The focal point is where all the reflected rays will meet; all the rays hitting the parabolic curve will meet, so it is a point of concentration [8]. The paraboloid has the unique property that light travelling parallel to the axis of a parabolic mirror will be reflected by the surface and concentrated at its focus (or conversely, a point source located at the focus will produce a parallel beam on reflection). This feature is illustrated in the figure below; parallel rays enter from the left and are brought to a focus at a single point.

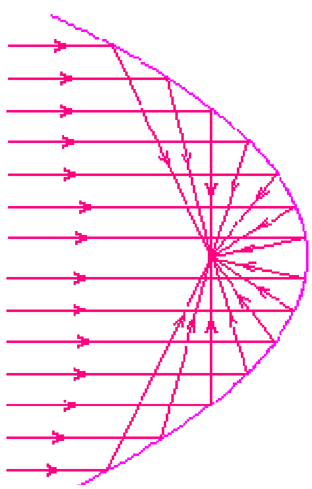

Figure 1: The focusing action of a parabola

Figure 2: Parabolic dish

It is the most powerful type of collector which concentrates sunlight at a single, focal point, via one or more parabolic dishes—arranged in a similar fashion to a reflecting telescope focuses starlight, or a dish antenna focuses radio waves. This geometry may be used in solar furnaces and solar power plants.
There are two key phenomena to understand in order to comprehend the design of a parabolic dish. One is that the shape of a parabola is defined such that incoming rays which are parallel to the dish's axis will be reflected toward the focus, no matter where on the dish they arrive. The second key is that the light rays

from the sun arriving at the Earth's surface are almost completely parallel. So if dish can be aligned with its axis pointing at the sun, almost all of the incoming radiation will be reflected towards the focal point of the dish—most losses are due to imperfections in the parabolic shape and imperfect reflection.

**Advantages**

- Very high temperatures reached. High temperatures are suitable for electricity generation using conventional methods like steam turbine or some direct high temperature chemical reaction.
- Good efficiency. By concentrating sunlight current systems can get better efficiency than simple solar cells.
- A larger area can be covered by using relatively inexpensive mirrors rather than using expensive solar cells.
- Concentrated light can be redirected to a suitable location via optical fiber cable. For example illuminating buildings.
- Heat storage for power production during cloudy and overnight conditions can be accomplished, often by underground tank storage of heated fluids. Molten salts have been used to good effect.

**Disadvantages**

- Concentrating systems require sun tracking to maintain Sunlight focus at the collector.
- Inability to provide power in diffused light conditions. Solar Cells are able to provide some output even if the sky becomes a little bit cloudy, but power output from concentrating systems drop drastically in cloudy conditions as diffused light cannot be concentrated passively.

**Parabolic reflector basics**

When looking at parabolic reflector antenna systems there are a number of parameters and terms that are of importance:

Focus: the focus or focal point of the parabolic reflector is the point at which any incoming ray will be concentrated. When radiating from this point, the rays will be reflected by the reflecting surface and travel in a parallel beam and to provide the required gain and beam width.

Vertex: this is the innermost point at the centre of the parabola.

Focal length: the focal length is the distance from the focus to the vertex.

Aperture: it is the opening or the area that it covers. For a circular parabola it is the diameter.

**Container volume calculation**

For a cylindrical shape, the volume is calculated by $V=\pi r^2 h$

We require a volume of 0.5L to 0.6L.

Let's take V=0.6L, and by setting the value of D to 8cm

$0.6*10^{-3}=\pi*(4*10^{-3})^2*h$

h=11.936cm.

The material to be used to manufacture the container is either aluminum or stainless steel due to health concern noting that they also have very good heat transfer ability.

Aluminum is preferred to stainless steel because our machine is portable, which means that weight is of our concern. Aluminum weight is 3 times less than stainless steel weight.

**Heat transfer calculation and time required**

Using the formula $Q = m*c*\Delta T$

Q = 0.6*4.18*50 =125.4 KJ =125400 J.
Now, the average daily energy provided by the sun ranges from $500W/m^2$ and $1000W/m^2$ [9]. These results can be checked using the daily light device.
So, for the purpose of our calculation, we will take an average value of $750W/m^2$.
Calculating the area of our parabola
Area = $(\pi*R/6*d^2)*((R^2+4*d^2)^{3/2} - R^{3)} = \pi*(25) / (6*25^2)*((25^2+4*25^2)^{3/2} - 25^3) = 0.333m^2$
After finding this value it can be said that the energy available or the total reflected energy is $A*750W/m^2$ = $0..333m^2*750W/m^2$ = 250W.
From previous calculation it was proven that we require 125400J to heat the water by $50^0$C.
So, the time required to heat the water will be: Q (J)/250(J/s) =125400/250 =501.6s t=8.5 min
This value is a theoretical value and it will be checked by experiments because we need to heat up the container at the beginning before heating the water and the container has a sheet metal thickness of 4mm.
The experiments that follow will show us the real or effective time required to heat the water by $50^0$C.

**Experimental values & Discussion**

| 1st experiment | Time | 11h30 | 11h41 | 11h52 | 12h01 |
|---|---|---|---|---|---|
| 852W/m2 | Temperature(0C) | 26 | 48 | 50 | 52 |

After performing the first experiment, a major conclusion must be made. From the time 11h41 to 12h01 we only had a $4^0$C change in temperature which is very small compared to the $22^0$C change in temperature at the beginning of the experiment from 11h30 to 11h41.From these values we could say that we have a major heat loss in our experiment.

| 2nd experiment | Time | 10h46 | 10h57 | 11h10 |
|---|---|---|---|---|
| 823W/m2 | Temperature(0C) | 27 | 39.5 | 50.5 |

In the second experiment, after closing the lid firmly at the top we had an improvement regarding heat losses except that the temperature didn't increase rapidly. This was due to the fact that, we had fluctuations in the energy delivered by the sun; the energy per meter squared that was read by the daystar meter was between $417W/m^2$ and $823W/m^2$.

| 3rd experiment | Time | 11h15 | 11h45 | 12h00 |
|---|---|---|---|---|
| 913W/m2 | Temperature(0C) | 28 | 53 | 63 |

In the third experiment we reached acceptable temperatures ($63^0$C) in 45min. These values could be improved by insulating the lid because as shown above by the results, our major heat loss is at this level.

**Comparing both methods**

By interpreting both methods, we can see that each option has advantages as well as disadvantages.

| criteria\method | 1st method | 2nd method |
|---|---|---|
| Operating Hours | 24h/24h | 6h |
| Time Required (hr) | 1.25-2 | 1 |
| Cost | 242$ | 42.5$ |
| Energy Needed | solar/direct input | solar only |
| weight | heavier | lighter |
| portable | yes | yes |

One of the main issues that should be highlighted is the operating time and the cost of the first method compared to the second method.
Depending on the usage, the consumer can decide which machine to choose. For household usage, customer select the first machine. On the other hand, if the consumer needs it for outdoor application, than the second machine must be chosen.

**Conclusion**

Due to toxic emissions our planet is going to the point of no return. So going green is what all manufactures should do in order to save our planet. However, going green has never been this easy with the solar powered coffee maker since efficiency is of great concern. You have probably also been hearing about the "solar revolution" for the last 20 years the idea that one day we will all use free electricity from the sun. This is a seductive promise on a bright sunny day. The sun shines approximately 1,000 watts of energy per square meter of the planet's surface, and if we could collect all of that energy we could easily power our homes and offices for free.
This report demonstrates the major effect of sunlight radiation versus time, in order to heat water required for coffee preparation. The results of the experiment are accurate but not precise with an average error of 10%. A systematic error in locating the focal point on the container is suspected in addition to minor random errors.
It is recommended to increase the surface area and obtain the paraboloid from a poured mold. Having done that, the theoretical results would have been more representative of the real experiment and the % error would have been reduced.
Furthermore, a similar experiment on the effect of heat transfer through the container would complement this study. A comprehensive discussion can then be made on the influence of heat transfer on increased efficiency.

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