PRINCE MOHAMMAD BIN FAHD UNIVERSITY

College of Engineering

Department of Mechanical Engineering

Fall 2019-20

Senior Design Project Report

Design and development of a solar-heating assisted thermoforming machine

In partial fulfillment of the requirements for the Degree of Bachelor of Science in Mechanical Engineering

Team 9

Team members

Student				
Name	Yousef Alaidarous	Abdulwahabe Almashoq	Abdulkarim Alzahrani	* Saad alammari
ID	201602438	201401989	201602730	201500166

Abstract:

Thermoforming is a manufacturing process where a plastic sheet is heated to a pliable forming temperature, formed to a specific shape in a mold, and trimmed to create a usable product. Thin-gauge thermoforming (one specific type of thermoforming process) is primarily the manufacture of disposable cups, containers, lids, and other products for the food, medical, and general retail industries. While, thick-gauge thermoforming includes parts as diverse as vehicle door and dash panels, refrigerator liners, utility vehicle beds and plastic pallets. An integral part of the thermoforming process is the use of electric heaters (most commonly used) to soften the plastic sheets to thermoforming temperatures, which requires considerable power input (depending on thickness and material of sheet). Current project, aims to design and develop a tabletop thin-gauge thermoforming machine utilizing solar-heating to heat plastic sheets, and make miniature disposable products for food industry. At large scale, the process, utilizing solar-heating will not only be helpful to reduce manufacturing cost but also minimize the dependency on classic ways of generating thermal power. This industry has huge commercial potential in KSA.

Objectives

- Design a renewable thermoforming process use a clean energy and typical sources of energy to produce products and goods.
- Production of simple shapes.
- Production of recyclable products.
- Reduce the cost.

Progress reports:

	SDP – MONTHLY MEETING REPORT
	Department of Mechanical Engineering **Prince Mohammad bin Fahd University**

SEMESTER:	Fall 19/20	**ACADEMIC YEAR:**	2019
PROJECT TITLE	Solar Heating Assisted Thermoforming machine		
SUPERVISORS	Dr. Muhammed Asaad, Dr. Mohamed Elmahdi Saleh		

Month 2: November

ID Number	Member Name
201500166	Saad Alammari
201401989	Abdulwahab Almashoq
201602730	Abdulkarim Alzahrani
201602438	Yousif Alaidarous

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Project background Previous Work Advantages and disadvantages of thermoforming	Saad Alammari	100%	
2	calculation of mass flow rate calculation of sucking Area Vacuum calculation of power	Abdulwahab Almashoq	100%	
3	Selection design of plastic sheet design of a reflective prabolic solar heater trough Selection design of sucking machine Vacuum	Yousif Alaidarous	100%	
4	Comparitive study calculation of power design of mold CAD design work	Abdulkarim Alzahrani	100%	

List the tasks planned for the month of March and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned
1	Subsystem 1 Overall Results, Analysis and Discussion Project Plan	Saad Alammari
2	Contribution of Team Members Project Execution Monitoring Challenges and Decision Making	Abdulwahab Almashoq
3	Project Bill of Materials and Budget	Yousif Alaidarous

	SDP – WEEKLY MEETING REPORT
	Department of Electrical Engineering Prince Mohammad bin Fahd University

SEMESTER:	Fall 2019	ACADEMIC YEAR:	19/20
PROJECT TITLE	Design and Development of a solar Heating assisted Thermoforming machine.		
SUPERVISORS			

Month 2: March

ID Number	Member Name
~~Saad~~ 201500166	Saad Alammari*
201602730	Abdulkarim Alzahrani
201401989	Abdulwahabe Almashog
201602438	Yousef Alqaidarous

List the tasks conducted this month and the team member assigned to conduct these tasks

#	Task description	Team member assigned	Progress 0%-100%	Delivery proof
1	Mile stone 3	All members	100%	AS
2	Midterm Presentation	All members	100%	AS
3	Video of the Prototype	All members	100%	AS

List the tasks planned for the month of March and the team member/s assigned to conduct these tasks

#	Task description	Team member/s assigned
1	Mile stone 6	All members
2	Completion of Project	All members
3	Final Presentation	All members

جامعة الأمير محمد بن فهد

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Student Name Student	ID:
1.Abdulkarim Alzahrani	201602730
2.Abdulwahabe Almashoq	201401989
3.Saad Alammari*	201500166
4.Yousef Alaidarous	201602438

Project Advisors: Advisor Name: Dr. Muhammad Asad

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Thermoforming is a manufacturing process where a plastic sheet is heated to a pliable forming temperature, formed to a specific shape in a mold, and trimmed to create a usable product. Thin-gauge thermoforming (one specific type of thermoforming process) is primarily the manufacture of disposable cups, containers, lids, and other products for the food, medical, and general retail industries. While, thick-gauge thermoforming includes parts as diverse as vehicle door and dash panels, refrigerator liners, utility vehicle beds and plastic pallets. An integral part of the thermoforming process is the use of electric heaters (most commonly used) to soften the plastic sheets to thermoforming temperatures, which requires considerable power input (depending on thickness and material of sheet). Current project, aims to design and develop a tabletop thin-gauge thermoforming machine utilizing solar-heating to heat plastic sheets, and make miniature disposable products for food industry. At large scale, the process, utilizing solar-heating will not only be helpful to reduce manufacturing cost but also minimize the dependency on classic ways of generating thermal power. This industry has huge commercial potential in KSA.

Acknowledgment letter:

Our final outcome and success could not have been without the continuous encouragement, support and guidance from our respected advisers. We are extremely privileged to have had the opportunity to learn and work under the direct supervision of Dr. Muhammed Asad. Also we owe our deep gratitude to our Co-Adviser Dr. Mohmed Elmehdi Saleh for sharing his knowledge and expertise with us. Our gratitude is also extended to Dr. Faramarz Djavanaroodi, chairman of the Mechanical Engineering department and Prince Mohammed University. All of this would have happened without the love and support of our lovely parents may god bless them all.

Table of Contents

CHAPTER 1

Project definition

The project utilizes the usage of sun heat to process our goal. First of all manufacturing the different parts and tools needed for the project. The aim here is to use a renewable energy to undergo the process. To elaborate, thermoforming process is he transformation of plastic sheets into the targeted 3-dimensional shape wither it was a cup holder, liquid bottle or even simple smart phone cover, using three main aspects (heat source, vacuum and pressure). Whereas the heat source goal is to heat the plastic sheets, vacuum and pressure goal is suck out the air between the mold and sheets to form a negative shape of the provided mold to the vacuum box. After the plastic sheets are heated it must go to the next stage, which is the placing of the sheets over the needed mold over the vacuum box. After turning the vacuum to suck the air out we must wait till the sheets are cold then we have to modify the external part of the sheets to fit the needed object.

Project objectives

The objectives of this project are design a renewable thermoforming process use a clean energy to produce products and goods harvest the sun benefits and reduce cost

Project specification

Our project is applicable to wide variety of shapes and size as long as we provide a proper vacuum box to the needed mold. The largest mold our box can handle must be in the region of (40x25) cm that has been selected for this project, which has the specifications as (40x25x10) cm

Project application

The main object of the thermoforming process is to shape the needed shape those shapes could be used in food, sports, home and office utilities. Also, it can be used in the kitchens.

CHAPTER 2

Project background

Creating plastic plates and plastic cups go through a well-known process called thermoforming. It is a process that involves heating a thermoplastic sheet to its melting point. Then stretching the sheet on one side of a mold, and then we let the sheet cools down to the desired shape. Depending on our desired final project we can choose the right polymer for us, there is a verity and each with a specific properties. Many methods are applied to thermoform plastics into our desired shapes, for example; vacuum forming, pressure forming, twin sheet forming and more…

Thermoforming has numerous applications that serve different industries and fields. Many corporations nowadays are switching to the renewable energy sources that are beneficial to our environment, and with new technology coming up every day renewable and clean energy can produce enough energy, as much as fossil fuels.

Vacuum Forming

Thermoforming is one of the eldest and most common methods of processing thermoplastics. Vacuum formed plastics are all around us and play a major part in our day-to-day lives. It’s a process that involves heating a plastic sheet and stretching it across a desired mold. A vacuum box is placed under the mold that provides vacuum pressure when the plastic sheet is placed on top of it, it will suck all the air in between the sheet and the mold in witch the desired shape is obtained instantly with low energy. It is hard to find a process that can match the low cost, efficiency, speed of replication for prototyping a small series of certain shapes is and that is easy to operate. One of the main advantages of vacuum forming is the speed at which products can be produced and the cost is much cheaper when comparing to injection molding. [15]

Pressure Forming

Pressure Forming is a combination of vacuum forming and also a downward pressure that is happening at the non-mold side of the heated thermoplastic sheet provided by a Pressure Box. Theoretically the maximum atmospheric pressure in the regular vacuum forming is 14.7 PSI. The added air pressure is up to 60 PSI on the non-mold side, and can increase the overall thermoforming pressure by as much as four times that of a traditional vacuum forming process. This added pressure allows for the capability to produce components and parts with sharper details. The mold side can look very similar to that of an injection mold part but it will have a much lesser tooling and also lower cost up to (20% – 30% less). Pressure Forming process cheaper than RIM (Reaction Injection Molding) and can offer major advantages when textured finishes is required, using a female molds, an ideal process for moderate production volumes on medium to large size products and parts. [15]

Pressure Forming can be a lifesaver when you want a low cost vacuum formed thermoplastic product with a good quality appearance, especially on small volume orders. Compared to the much expensive injection molding, Pressure Forming process captures the same sharpness of design and is proving to be a godsend to the plastics industry. Designers can now assimilate further features into products allowing a better look and feel. Pressure Forming can increase the visual apparent desirability of a molded plastic product. [12]

Twin Sheet Forming

Twin sheet thermoforming is a process that is not very well known, it has always been hidden in the shadows of vacuum forming and pressure forming in thermoforming industry. Pressure forming and vacuum forming have been around for years and are widely accepted. Nonetheless, the challenging process in this twin sheet thermoforming process is that it is both vacuum and pressure forming. The two plastic sheets in twin sheet forming must be in complete aligned with each another. This is to make sure that the plastic can be synced with their pressed points. Pressed points are the areas where the two desired molds are pressured together. There is no place for mistakes during the fusion of the two sheets. They have to be perfectly synced in order to join together correctly. [9]

The Twin sheet process allows the hot air to be trapped inside. This may cause the board to collapse. To fix this, holes are placed along the one side of the board that acts as a ventilation system. Cool air is comes in and the holes are designed in a way that conceals the presence. Painted or unpainted, surface finishing is important when thermoforming. Shadowing, a phrase used that mean noticeable deviation in surface finish, can happen on edges near where the twin sheets are pressed together. To erase shadowing, the mold can be bead blasted which will give the board a textured finish. [9]

Energy Sources

Electricity

Electric Heating is a conversion process that switch electrical energy into heat energy. Most common applications are water heating for showers and warm baths, space heating for warm cozy gathering with family and friends in winter, and also industrial process such thermoforming process. Therefor an electric heater is a device that converts electrical energy into heat energy. Electric heaters consist of electric resistors, which are considered as the heating element. Using electricity for heating is becoming much more common nowadays with privet residences and also public buildings. Even though electric heating mostly costs much more than energy obtained from combustion fuel, the accessibility, cleanliness and the small space needs of electric heaters do often justifies its use. Also from electric coils or strips used in different patterns we can provide heat, such as baseboard radiation in part or in all of a room, also convectors in or on the walls, or under windows. We can also implant heating elements or wires in ceilings or floors to radiate low heat temperature into a desired space. Also, by the adding a heat pump the overall cost of electric heating could be reduced undoubtedly. [8]

Solar rays

Solar heating is mostly used when heating water for domestic use, it is rarely used to in industries or for huge productions processes. But that does not mean that it is not possible. Experiments were conducted that shows when concentrating solar rays to a point the heat hitting that spot will increase significantly. Which shows that if enough sunrays are pointed at the right angle towards the product of thermoplastic sheet it will melt after a short while. Using curved glass to convert the radial rays that are coming from the sun is the key to this process, and knowing exactly the right angle is so important to capturing as much solar rays as possible, also the side of the curved glass that will redirect the solar rays the desired direction is very important, and of course the most import element is have a sun. And this is a disadvantage that only clear sunny days are applicable for capturing this great free clean energy. [7]

Fossil fuels

Fossil fuels have been the most used energy provider in the world for decades now, and that is due to the tremendous amount of fossil fuels that are available to our disposal. Even though we know these can be dangerous to our lively hood we still are continuing and willingly using and burning more than before. With demand on fossil fuels growing the carbon emissions are covering up the ozone, which is the primary leading reason of global warming. With world leaders not taking action to prevent over use of fossil fuels and implementing laws against companies to switch to cleaner better energy then it will only get worse for next generations. [1] [2]

Shown below a table that is suggesting catalytic gas can be cheaper than electric heaters, this table is posted a website of the companies that are experts in implementing and installing electric and gas heaters. [3]

	Gas Catalytic	Electric IR
Energy Cost	☼	
Capital Cost		☼
Cut Sheet Applications	☼	
Inline Thermoforming		☼
Automatic Controls	☼	☼
Familiarity Of Use		☼
Longevity	10,000 - 15,000 hours	20,000 hours
Maintenance	May be refurbished	Must be replaced

Figure 1 [8]

Tools

Vacuum

A machine that suck air from one side into the other, in our case it will suck the air from under the thermoplastic sheet to provide and atmospheric pressure vacuum.

Sucking box

Here is where atmospheric pressure vacuum will take place. After placing the mold on top of the sucking box we put the thermoplastic sheet on top of it and suck all the air that will allow the plastic sheet to transform to the desired shape.

Heat sources

The plastic sheet will need to be heated to its softening temperature. That will give the sheet a bubbly feeling that shortly after is inserted into the sucking box for it to be stretched on a desired mold.

Mold

A mold is the shape that the plastic sheet will take once is cooled down.

Thermoplastic sheet

Is the product that we want to have. Choosing the right polymer is very important, and it all depend on what our final product will be, based on that we can choose the right polymer.

Table 1 [4][6]

Material:	Melting point Temp:	Heat Deflection Temp:	Tensile Strength:	Shrink Rate:
Polylactic Acid (PLA) 	157˚-170˚ C	49˚-52˚ C	61-66 MPa	0.37-0.41%
Acrylonitrile butadiene Styrene (ABS) 	105˚ C	98˚ C	46 MPa	0.5-0.7%
Polystyrene (PS) 	210˚-249˚ C	95˚ C	53MPa	0.3-0.7%

Previous work:

Thermoforming is considered as one of the oldest methods of forming materials into useful use. There are many methods or types of thermoforming. The most common methods, which are used in the current time, are vacuum, pressure and twin sheet forming. First let see how vacuum forming works based on British Plastic Foundation First we will need a sheet of plastic usually high impact polystyrene, a mold, vacuum forming machine, tumble clamps to hold the plastic sheet properly, platen which is the platform the mold sits on, heater and a heat controller, platen lift to lower and raise the platform. First step is to heat the plastic sheet from above until it is comes soft and flexible, and then we raise the mold into the plastic from below. Finally the air is vacuumed from below forcing the malleable plastic comes to the mold making the plastic taking the shape of the mold. This method is characterized by the low cost of implementing, simplicity, high speed and efficiency of prototyping. [2] [3]

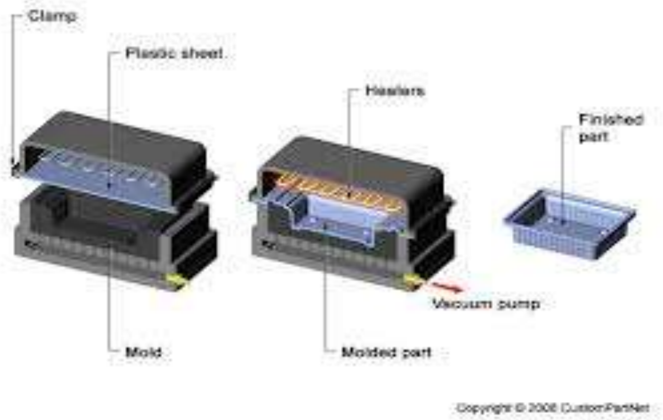

Figure2

Figure 3

The second type of thermoforming is pressure forming. Based on Universal Plastics – Sutton project, 68 Providence Rd, Sutton, MA 01590, United States. Pressure forming considered as an advanced plastic manufacturing process, where we can create complex geometries and detailed shape. Pressure forming is more enhanced and improved than the vacuum forming process. When using traditional vacuum forming, creating a vacuum on the mold side of the sheet is forming the plastic parts. Since the atmospheric pressure is 14.7 pounds per square inch (PSI) this is the maximum theoretical forming pressure that vacuum forming can provide. When using pressure forming, a pressure box is added to the non-mold side of the sheet. The heated plastic sheet makes the seal between the pressure box and the mold. Air pressure up to 60 PSI is then can be added to the non-mold side of the sheet in addition the vacuum is pulled on the mold side. This can increase the effectiveness of the forming pressure 3 to 4 times than what vacuum forming can produce. Also, some of the advantages of pressure forming are having the ability to create very large shapes, rapid prototyping and quick time to market plus it considered as low cost process of forming compared to other process. [5]

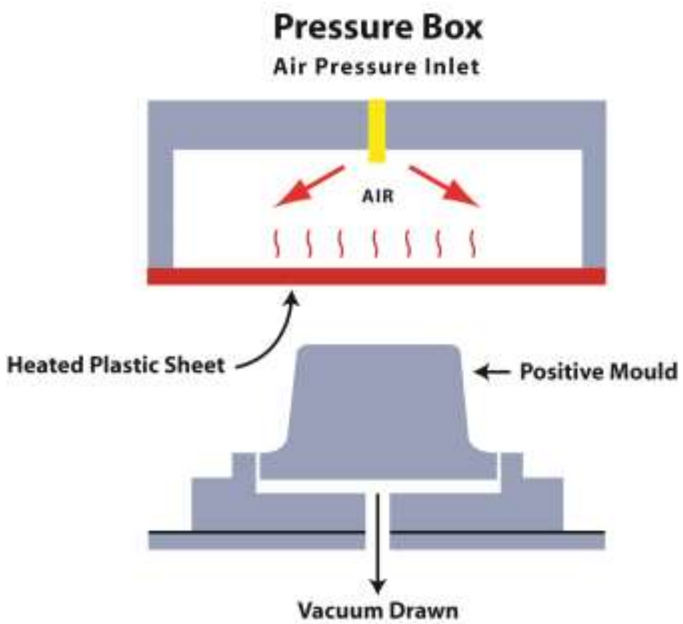

Figure 4

Third type is called twin sheet thermoforming, based on United States Patent number 5,407,632, Inventors: James P. Constantine, Mt. Clemens; Raymond H. Gosnell, Plymouth, both of Mich. In order of producing a twin sheet thermoformed structure, a mold must be provided with a major rib producing structures separated into discrete tabs with gaps between tabs. The first sheet of material is fused or merged by itself upon drawing the material into the gaps between tabs from both sides of the gap. The material is drawn into the gaps merged upon contact with the material being drawn into the gap from the other side forming a cross rib which tends to stabilize the sidewalls of the major rib. The first sheet is then fused to a second sheet of material to make a twin sheet structure. Some the advantages of twin sheet forming are having a high strength and stiffness with low weight plus low tooling cost. [13]

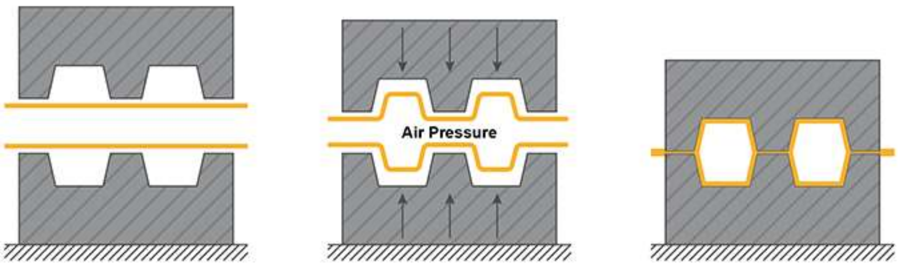

Figure 5

Figure 6

Comparative Study

First project:

Based on the first project above which is done by British Plastic Foundation they used on their project a heater plus a heat controller as a heating source, which considered as a very typical heating source. Also, they placed the mold in said a platform and used a platen lift to lower and raise the platform. In addition, they used a high impact polystyrene material, as for the sucking process they used a vacuum former machine and for holding the plastic they used toggle clamps. In this project they deepened on electricity very heavily by using electricity to generate all their machines. [15]

Second Project:

Second project I would like to mention is the Twining sheet thermoforming. This type of thermoforming requires two sheets of thermoplastics; it is then placed on top of each other in a synchronized way using two molds. The two sheets have to be on top of each other exactly, or then the product will fail, it has to have a very thin thickness in which it will allow the product to become stiffer and stronger. In comparison to our project we will have only one mold, and also our product won't become as stiff and strong as the Twinning sheet. [16]

In comparison:

The different between these two project and ours. Our project and the first project are pretty similar but it has some differences, such as the energy source. For example: in the first project their source is coming from electricity, which is pretty costly and have its footprint on the environment. On other hand our project is getting its heat source from the sunrays directly, where we will use a curved glass that will convert the sunrays into the thermoplastic sheet directly. Secondly, in the first project inserted their mold inside a platform machine, in our project the mold will be placed on a homemade wooden box that is closed from all sides to trap air except the top part, where we placed many small holes that will provide us with the vacuum pressure we need.

Chapter 3: System Design

3.1 Design Constraints and Design Methodology

3.1.1 - Geometrical Constraints:

When we decided to take this project we thought that it would be an easy project without any challenges. But with the passage of time we knew directly what parts would be challenging. The first part was the heating source; our primary goal in the project is to use clean energy as a heating source. In other words we will utilize the sun to generate heat, hence we brought solar energy panels to generate electricity to start an oven. But we faced a problem the electricity generated from the panels was not enough to make the oven work, we needed a large number of panels to make that work and that was very expensive. But we managed to come up with an alternative idea. Which is coting a plate with a reflecting material that reverse the sunrays to a specific area. The second issue was the sucking process; the vacuum that we used wasn't sufficient enough to suck in the material. In other similar project they used pressure to suck the material in by using advanced machines, but in our case we had to use a vacuum. We managed to solve this problem by reducing the area of the box and the used material. The negative aspect here is that we cannot use materials with large dimension thus we are forced to create specific sizes of moulds. [6]

3.1.2 - Sustainability:

As for sustainability our project may have some issues, we may have some maintenance and replacement of some parts. Like the wooden box, we are using screws that are holding the box, with time they may get loose so we can tight them up or replace them. As for the vacuum after a while it must go under maintenance. For the material we are using, they are easy to obtain, there are many local supplier so we don't have to worry about that. The holders that we are using they are made of steel so with time defiantly they will get corroded thus maintenance should be applied or replacement. The reflection material that are used it must be changed after several uses. As for energy like what is mentioned we are depending on renewable energy as the main source of energy so in this part we are doing fine. [7]

3.1.3 - Environmental:

Our project is considered as an environmental-friendly project, because we are using the solar energy and electricity as energy suppliers. Theses two sources of energy do not effect the environment in a negative way. Plus the products that we produce are mostly plastics, which can be recycled. [14]

3.1.4: Social:

Our system consider as a medium difficulty project to assemble or to create. With some engineering knowledge you can build this system to generate heat and make different shapes of plastics using thermoforming. Our idea of thermoforming it is rarely used in the kingdom of Saudi Arabia so with our project we want to bring something new to our society. By making them understand the concept behind our project, plus the amount of money needed to build this system is low huge number of people can afford it. [13]

3.1.5: Economic:

As for the economical aspect, heat is a fundamental and a basic ingredient in our project without it the system will not work. The new idea in the project is to generate heat by using the sunlight, by designing a specific shaped duct can absorb the sunlight. We will not use a typical heating source as an oven or torches etc. As we all know using such a devices to generate heat need a lot of electricity and energy, which will cost allot of money, thus in our case we will save money by utilizing the sun. In addition, we will use a hand made wooden box and a small vacuum machine, which require small amount of energy. [15]

3.1.6: Safety:

Safety is one of the most important requirements in any project. Based on the tools and the elements that we used to assemble our project, none of them can create a huge danger on the workers and the environment. Except when the material is hot caution must be considered, even thou as we side we don't want to melt the material so we will not reach the melting temperature hence the material will not be that hot to create severe damage. [15]

3.1.7: Ethical:

There are similar projects that have the same concepts of ours. By absorbing them we took some concepts and managed to develop new ideas. Improving the safety, economical, social, environmental, the sustainability and the engineering constrain sides, did that. [11]

3.2 Engineering Design standards

The main objective from this part of the design is to clarify the particles that we used to assemble and build the project. The standards that we used are The American Society for Testing and Materials (ASTM), ANSI, Solid-Works and NSK. We will utilize the standards to classify what type of material has been selected, as well as giving the dimensions and stating which material has been designated for each component. The components are: screw, bearing, plastic sheet, vacuum box, mould and the sucking machine (vacuum). [4] [5]

3.2.1: Screw

The screw has been chosen from the toolbox from the Solid-Works® software.

1- Length: 80 mm 2- Thickness of the head: 5 mm 3- Diameter of the head hex: 16 mm

3.2.2: Bearing

Ball Bearings 6300ZZ: OD 35-mm, and width 11-mm the standard of the bearing is: Deep Groove Ball Bearing 6300ZZ [10].

3.2.3: Plastic sheet

Thickness: 1-30 mm

Working temperature: (-50C to +70).

Size: 680*1230mm, 1000* 2000mm.

3.2.4: Vacuum box:

High: 7cm

Width: 10cm

Length: 7cm

3.2.5: Parabolic trough:

Diameter: 30cm

Thickness: 4cm

Length: 1.5m

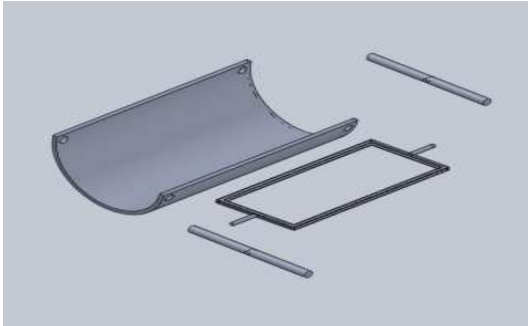

Figure 7

3.2.6: Sucking machine:

Power: 2300 W

Capacity: 22L

Electricity needed to operate: 22 V

3.2.7: Mould:

Upper diameter: 65mm

Lower diameter: 45mm

Height: 90mm

Figure simulation is illustrated in the figure bellow.

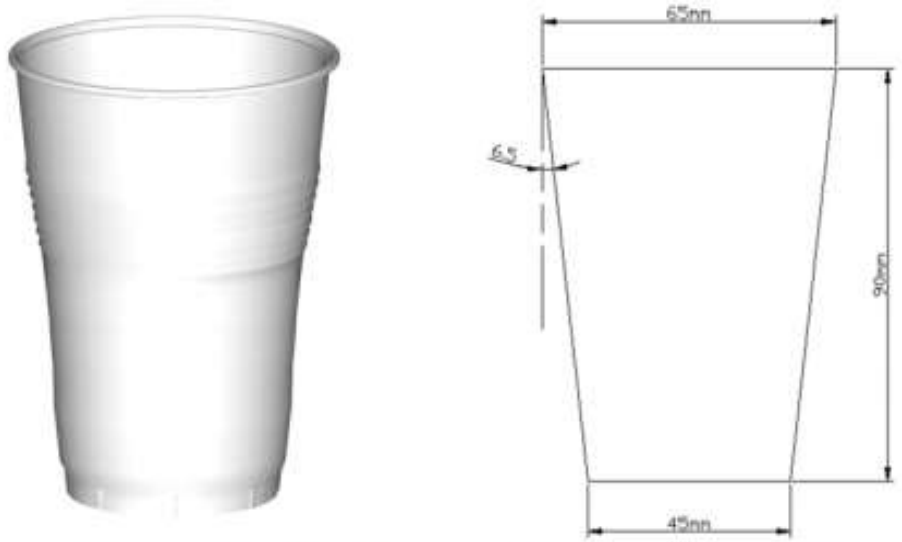

Figure 3a: Full disposable cup details. Figure 3b: Dimensions of disposable

Figure 8

3.3 Theory and Theoretical Calculations:

3.3.1: Thermoforming theory:

Thermoforming of polymers is a generic term for a group of processes that involves the forming or stretching of a preheated polymer sheet on a mould producing the specific shape. It is considered to be one of the oldest methods of processing plastic materials. The process which uses the vacuum negative pressure force to stretch this heated polymer sheet on a mould is called vacuum forming or vacuum thermoforming. Specifically, this is the forming technique and/or stretching where a sheet of thermoplastic material is preheated by a heating system, and forced against the mould surface (positive or negative) by means of the negative vacuum pressure produced in the space between the mould and sheet by mould suction holes and a vacuum pump which “sucks” the air from the space and “pulls” the sheet against the surface of the mould, transferring it, after cooling and removing excess material to shape it. The typical sequence of this technique by Ghobadnam and it is presented bellow in figure 9. [1]

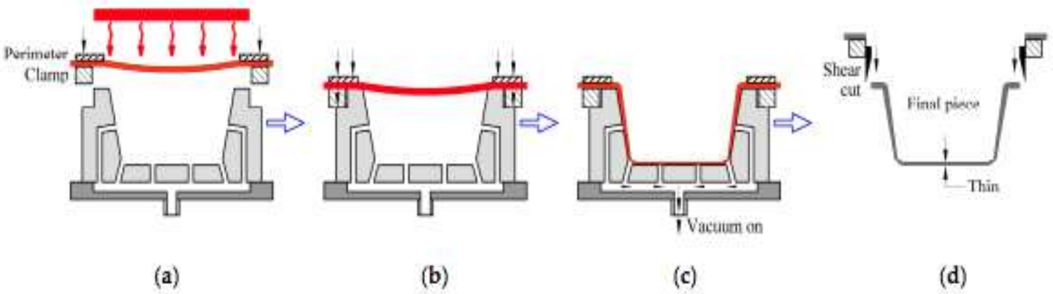

Figure 1. Schematic of basic vacuum thermoforming. (**a**) Heating; (**b**) sealing or pre-stretch; (**c**) forming and cooling; and (**d**) demolding and trimming.

Figure 9

Radiation analysis

To understand the radiation regions and the where is it effective, we must study the locations that has available solar radiation in order to collect energy form the location. It’s considered to be essential to do feasibility study to mark the expectations and weather if it’s good enough. The feasibility study of the solar power plants will evaluate the project as a whole. Moreover, long-term measured data of solar radiation are available in modern countries that estimate the solar energy availability in the area. Nevertheless, the other locations where long-term data are not available, different methods and physics are used to estimate the information about solar energy. To explain solar energy is in the form of electromagnetic radiation with wavelengths ranging from about 0.3 µm (10−6m) to over 3 µm, which correspond to ultraviolet (less than 0.4 µm), visible (0.4 µm and 0.7 µm), and infrared (over 0.7µm); most of this energy is concentrated in the visible and the near-infrared wavelength range. The incident solar radiation, sometimes are called insolation, is measured as irradiance, or the energy per unit time per unit area (kW/m2). The average amount of solar radiation falling on a surface normal to the rays of the sun outside the atmosphere of the earth, extra-terrestrial insolation, at mean earth-sun distance Do is called the solar constant, Io. Lately, new measurements have found the value of solar constant to be 1366.1 W/m2. [2]

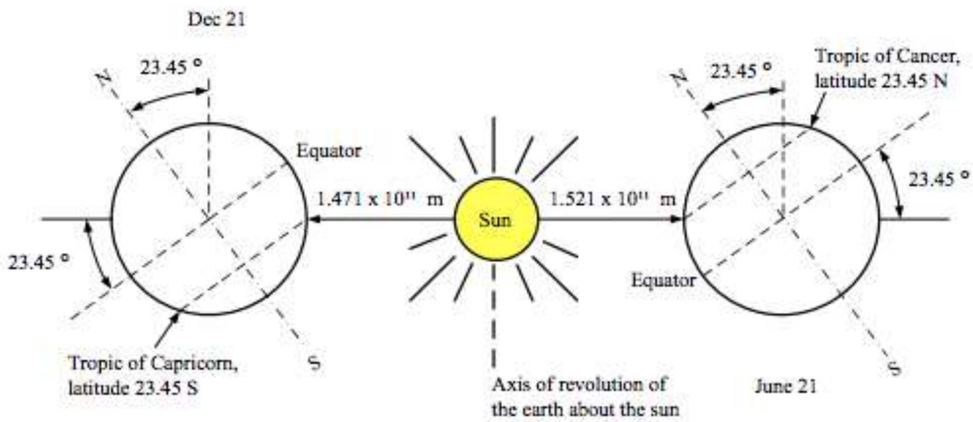

Figure 10: illustrating Radiation analysis

Solar Angles Analysis:

The variation in seasonal solar radiation availability at the surface of the earth can be understood from the geometry of the relative movement of the earth around the sun. The distance between the earth and the sun changes throughout the year, the minimum being 1.471×1011 m at winter solstice (December 21) and the maximum being 1.521×1011 m at summer solstice (June 21). The year round average earth sun distance is 1.496 × 1011 m. The amount of solar radiation intercepted by the earth, therefore varies throughout the year, the maximum being on December 21 and the minimum on June 21 (Figure 11). The axis of the earth's daily rotation around itself is at an angle of 23.45 ° to the axis of its ecliptic orbital plane around the sun. This tilt is the major cause of the seasonal variation of the solar radiation available at any location on the earth. The angle between the earth-sun line (through their centre) and the plane through the equator is called the solar declination angle, δs (Figure 2.2). The declination angle varies between -23.45° on December 21 to +23.45° on June 21. [2]

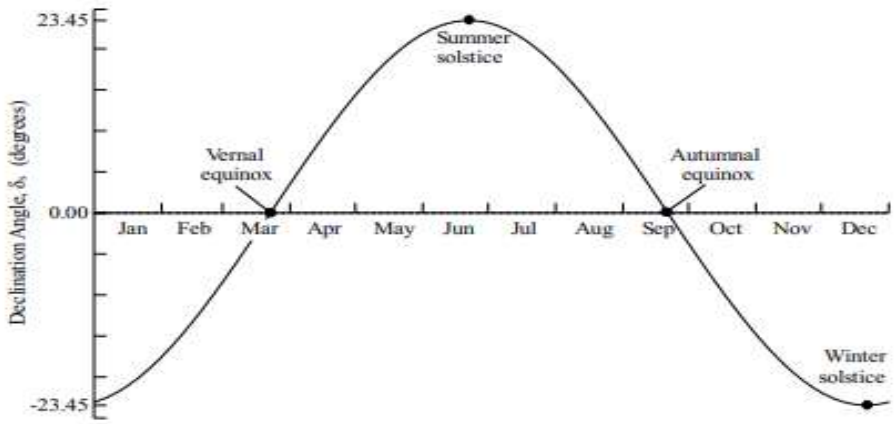

Figure 2.2 Variation of the declination angle, δ_s, throughout the year

$$\delta_s = 23.45° \sin\left[\frac{360\,(284+n)}{365}\right]$$

Figure 11: Illustrating angle analysis for solar system.

Theoretical calculation:

Steps of the Developed Modelling the present modelling can be separated into five steps.

STEP 1: The thermal losses from the cover to the ambient are radiation and convection losses, and they can be written as below. At this point, it is important to state that the contact thermal losses are neglected.

$$Q_{loss} = A_{co} \times \varepsilon_c \times \sigma \times \left(T_c^4 - T_{am}^4\right) + A_{co} \times h_{out} \times (T_c - T_{am}) \qquad (1)$$

Figure 12 [3]

The cover temperature is assumed to be close to the ambient temperature because of the existence of an evacuated tube collector. Thus, using Taylor series, it can be written:

$$T_c^4 - T_{am}^4 \approx 4 \times T_{am}^3 \times (T_c - T_{am}) \qquad (2)$$

Figure 13 [3]

Equation (2) is an important assumption of this work and its validity is tested by the comparisons between this and other models, which are given in Section 3. Using Equations (1) and (2), it can be written:

$$Q_{loss} = \left[A_{co} \times \varepsilon_c \times \sigma \times 4 \times T_{am}^3 + A_{co} \times h_{out}\right] \times (T_c - T_{am}) \quad (3)$$

or

$$Q_{loss} = K_1 \times (T_c - T_{am}) \quad (4)$$

with

$$K_1 = A_{co} \times \varepsilon_c \times \sigma \times 4 \times T_{am}^3 + A_{co} \times h_{out} \quad (5)$$

STEP 2

Figure 14 [3]

STEP 2: The present model is developed for steady-state conditions. In this case, the thermal losses of the absorber to the cover are equal to the thermal losses of the cover to the ambient. The thermal losses of the absorber to the cover are only radiation losses because of the vacuum between the absorber and the cover (there are no convection thermal losses):

$$Q_{loss} = A_{ro} \times \varepsilon_r^* \times \sigma \times \left(T_r^4 - T_c^4\right) \quad (6)$$

with

$$\varepsilon_r^* = \left[\frac{1}{\varepsilon_r} + \frac{1-\varepsilon_c}{\varepsilon_c} \times \frac{A_{ro}}{A_{ci}}\right]^{-1} \quad (7)$$

Figure 15 [3]

The Equation (6) can be written as below. It is important to state that the cover has been assumed to radiate to the ambient conditions.

$$Q_{loss} = A_{ro} \times \varepsilon_r^* \times \sigma \times \left(T_r^4 - T_{am}^4\right) - A_{ro} \times \varepsilon_r^* \times \sigma \times \left(T_c^4 - T_{am}^4\right) \quad (8)$$

Figure 16 [3]

Using Equations (2) and (4), it can be written:

$$T_c^4 - T_{am}^4 = \frac{4 \times T_{am}^3}{K_1} \times Q_{loss} \quad (9)$$

Figure 17 [3]

Using Equations (8) and (9), it can be said:

$$Q_{loss} = A_{ro} \times \varepsilon_r^* \times \sigma \times \left(T_r^4 - T_{am}^4\right) \times \left[1 + \frac{4 \times T_{am}^3 \times A_{ro} \times \varepsilon_r^* \times \sigma}{K_1}\right]^{-1} \quad (10)$$

or

$$Q_{loss} = K_2 \times \left(T_r^4 - T_{am}^4\right) \quad (11)$$

with

$$K_2 = A_{ro} \times \varepsilon_r^* \times \sigma \times \left[1 + \frac{4 \times T_{am}^3 \times A_{ro} \times \varepsilon_r^* \times \sigma}{K_1}\right]^{-1} \quad (12)$$

Figure 18 [3]

STEP 3: The useful heat can be calculated using the energy balance in the fluid volume:

Qu = m × cp × (Tout − Tin) (13)

Furthermore, it can be calculated using the heat transfer from the receiver to the fluid:

Qu = Ari × h × (Tr − Tf m) (14)

At this point, it can be said that the heat transfer coefficient in the flow has been assumed to be the same along the absorber tube. The mean fluid temperature can be estimated as:

Tf m = (Tin + Tout) / 2 (15)

Using the Equations (13)–(15), it can be written:

$$Q_u = \left[\frac{1}{A_{ri} \times h} + \frac{1}{2 \times m \times c_p}\right]^{-1} \times \left(T_r - T_{in}\right) \quad (16)$$

or

$$Q_u = K_3 \times \left(T_r - T_{in}\right) \quad (17)$$

with

$$K_3 = \left[\frac{1}{A_{ri} \times h} + \frac{1}{2 \times m \times c_p}\right]^{-1} \quad (18)$$

Figure 19 [3]

STEP 4: The goal of this step is to simplify the Equation (11). The following transformation of the Equation (11) can be written:

$$Q_{loss} = K_2 \times \left(T_r^4 - T_{in}^4\right) + K_2 \times \left(T_{in}^4 - T_{am}^4\right) \qquad (19)$$

Figure 20 [3]

Generally, the temperature difference between receiver and fluid is not so high. Thus, using Taylor series, it can be written:

$$T_r^4 - T_{in}^4 \approx 4 \times T_{in}^3 \times \left(T_r - T_{in}\right) \qquad (20)$$

Figure 21 [3]

Using Equations (17) and (20), it can be written:

$$T_r^4 - T_{in}^4 \approx \frac{4 \times T_{in}^3}{K_3} \times Q_u \qquad (21)$$

Using Equations (19) and (21), it can be said:

$$Q_{loss} = \frac{4 \times T_{in}^3 \times K_2}{K_3} \times Q_u + K_2 \times \left(T_{in}^4 - T_{am}^4\right) \qquad (22)$$

Figure 22 [3]

STEP 5 The energy balance in the absorber indicates that the absorbed energy is converted into useful heat and to thermal losses. At this point, a uniform heat flux over the absorber is assumed. The absorbed energy is equal to the optical efficiency multiplied by the direct beam solar irradiation. Thus, it can be written **[3]**

$$\eta_{opt} \times Q_s = Q_u + Q_{loss} \tag{23}$$

Using Equations (22) and (23), it can be written:

$$Q_u = \left[\eta_{opt} \times Q_s - K_2 \times \left(T_{in}^4 - T_{am}^4\right)\right] \times \left[1 + \frac{4 \times T_{in}^3 \times K_2}{K_3}\right]^{-1} \tag{24}$$

or

$$Q_u = K_4 \times Q_s - K_5 \times \left(T_{in}^4 - T_{am}^4\right) \tag{25}$$

with

$$K_4 = \eta_{opt} \times \left[1 + \frac{4 \times T_{in}^3 \times K_2}{K_3}\right]^{-1} \tag{26}$$

and

$$K_5 = K_2 \times \left[1 + \frac{4 \times T_{in}^3 \times K_2}{K_3}\right]^{-1} \tag{27}$$

Figure 23 [3]

3.4 Product subsystems and selection of component:

For this project, it is divided into two different major parts. The first part is a parabolic trough solar collector, and the second part is a thermoforming-sucking box.

For the first part it can be divided into two minor parts, a Solar Collector and Plastic Sheet Holder. The solar collector will include an aluminum sheet, which has the ability to reflect significant amount of solar rays back from the surface of the sheet. The Aluminum sheet will be placed on top of a parabolic surface, which will give it the desired shape with a specific focal point of the reflected solar rays. Plastic sheet holder is going to include a square metal frame that will come in the size of the plastic sheet. It will hold it on the top of the Parabolic Trough for the period of time that is needed for the sheet to melt.

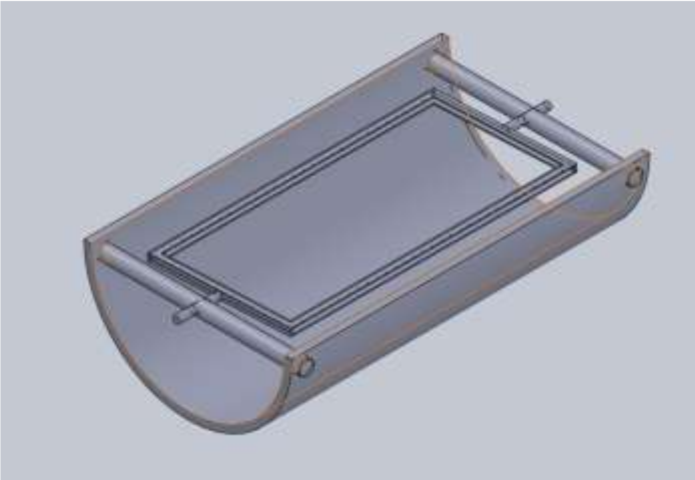

Figure 24

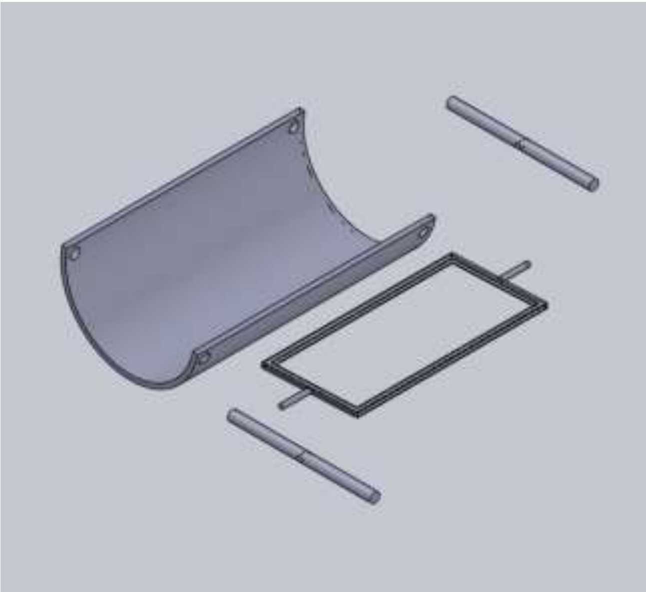

Figure 25

For the second part it will also be divided into two minor parts, a vacuum machine and a sucking box. We made sure that our vacuum machine could provide enough power to provide us with the desired vacuum pressure to make our final shape. The sucking box is made with specific dimension related to our plastic sheet to provide us with the final product.

Figure 26

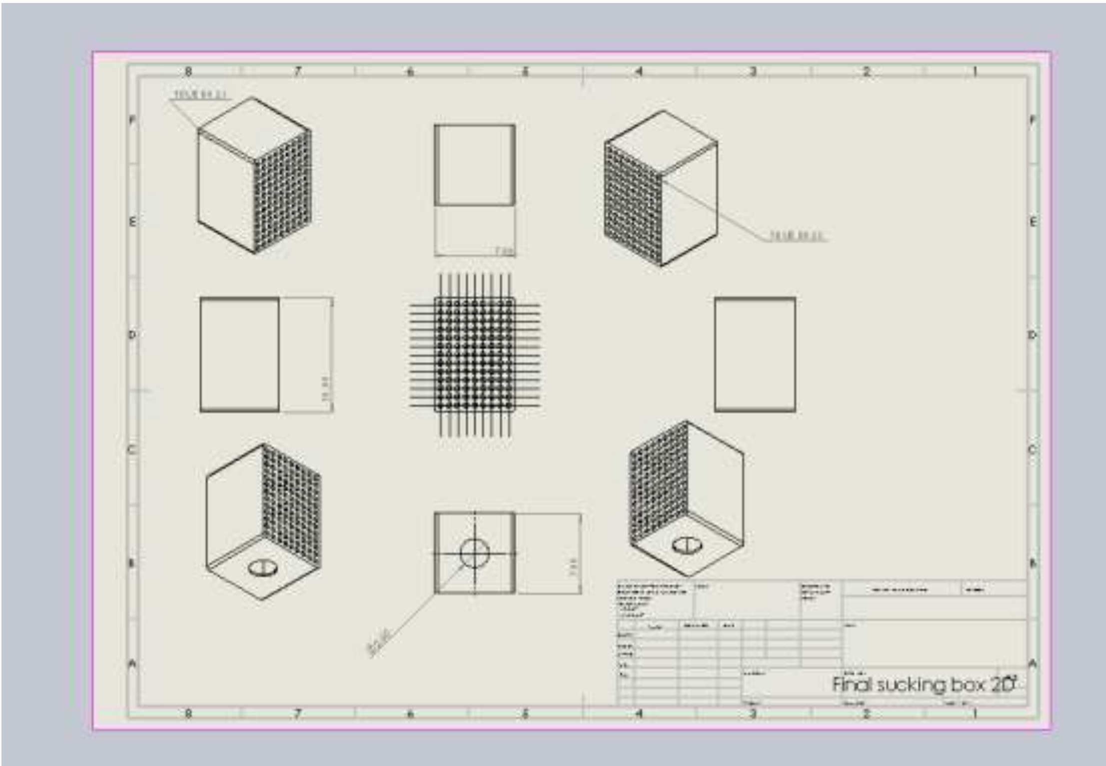

Figure 28

3.5 Manufacturing and assembly (implementation)

Our thermoforming project consists of multiple parts and components. To illustrate, the first part is to design a reflective surface (Aluminium foil sheet or mirror) to gather the sunrays and energy to a specific focal point. In that point, the plastic sheets will be placed to absorb that heat and form to a workable material. As you know, with increasing the temperature of the work piece, the plastic sheets will be more eligible to expand and give you more delicate designs. After reaching that step, the work piece will transfer to another station, where a well finished mould will be placed above a wooden box that have been drilled to insure the vacuum pulls up all the air. With the plastics sheets in that form, it will be much easier to encases the needed mould with the plastic sheets perfectly. To insure no leakage of air pressure when using the wooden box, we have use wood glue and tape inside the compartment of that box. The purpose of choosing a wood box is to use the earth's recycled goods to limit the pollution even if it's a small effort in that huge world.

Chapter 4: System Testing and Analysis

4.1 Experimental Setup, Sensors and data acquisition system

4.1.1: Infrared Thermometer:

For this section we had two setups. In the first setup we wanted to measure the temperature of the plastic sheet when we expose it to the heater. Thus we used an infrared thermometer to measure the temperature. Infrared Thermometer is a thermometer that measure temperature without contact from a specific distance by using radiation, plus leaser is used in this device to help aiming at the desired object. How did we used it? We simply wanted to measure the temperature of the plastic sheet when we expose it to the heater in order to know if the material reached it softening temperature.

Figure 1

Figure 2

Specifications:

Temperature range	-30°C to 500°C (-22°F to 932°F)
Accuracy	±1.5°C or ±1.5% of reading, whichever is greater -10°C to 0°C: ±2.0 -30°C to -10°C: ±3.0
Response time (95%)	< 500 ms (95% of reading)
Spectral response	8 to 14 microns

Emissivity	0.10 to 1.00
Optical resolution	10:1 (calculated at 90% energy)
Display resolution	0.1°C (0.2°F)
Repeatability of readings	±0.8% of reading or < ±1.0°C (2°F), whichever is greater
Power	AA battery
Battery life	10 hours with laser and backlight on

Physical Specifications

Weight	255 g (8.99 oz)
Size	175 x 85 x 75 mm (6.88 x 3.34 x 2.95 in)
Operating temperature	0°C to 50°C (32°F to 122°F)
Storage temperature	-20°C to 60°C (-4°F to 140°F), (without battery)
Operating humidity	10% to 90% RH non-condensing at 30°C (86°F)
Operating altitude	2000 meters above mean sea level
Storage altitude	12,000 meters above mean sea level
IP rating	IP 54 per IEC 60529
Drop test	3 meters
Vibration and shock	IEC 68-2-6 2.5 g, 10 to 200 Hz, IEC 68-2-27, 50 g, 11 ms

EMC	EN 61326-1:2006 EN 61326-2:2006	
Standards and agency approval	Compliance	EN/IEC 61010-1: 2001
	Laser safety	FDA and EN 60825-1 Class II

Vacuum gauge:

In the second part of our setup, we wanted to measure the negative pressure produced by the vacuum. The device that we used in this part called Vacuum gauge, it is a pressure gauge which is used to measure pressures lower than the ambient atmospheric pressure which is placed as the zero point in negative values. By using this gauge we managed to calculate the required pressure.

Figure 4

Specification:

Product name	1.5inch-40mm ABS case brass connection bottom vacuum pressure gauge
Model number	YZ-40A
Diameter size	**(1.5”)40mm**; 2.5”(63mm); 3.5”**(**75mm); 4”(100mm); 6”(150mm); 8”(200mm); 10”(250mm) etc.
Case/cover	**ABS case**
Window	**PC glass**
Connection	**brass** **bottom**(back/back with clamp or flange etc.)
Thread	G/PT/NPT 1/8 1/4 1/2, M10*1, M14*1.5,M20*1.5 etc.
Bourdon tube	**phosphor bronze**
Movement	**brass**
Dial plate	aluminum
Pressure range	-0.1~100mpa
Accuracy	1.60%, 2.50%

Table 4.1: Testing parameters

Testing parameters	Objective
Infrared Thermometer	To measure the temperature
Vacuum gauge	To measure the pressure

4.2 Results, Analysis and Discussion

Table 4.2: Data of the results

By knowing the specifications of our plastic sheet and applying the correct formulas, plus working with a vacuum machine that operate at Negative 20 kPa / 2300W.

We need only (12-14 s) to heat up the plastic then our project will start working.

<u>Formulas:</u>

Formula	Unit
$Q = mc\Delta T$	J
$t = Q \div P$	S

<u>Material specifications:</u>

PVC	**Thickness: 0.2 mm** **Softening temperature: 80 C** **Melting temperature: 100 C-180 C**

Chapter 5: Project Management

5.1: Project Plan

In this project either one or more members have done the required tasks. Listed below is all information concerning the tasks, the team members, and duration of each task completed. In table 5.1 you will see the list of tasks & durations. And table 5.2 you will see the assigned members.

#	**Task**		**Start**	**End**	**Duration (days)**
1	Introduction		9/5/2019	9/7/2019	3
2	Chapter 2: Literature Review	Project Background	9/10/2019	9/17/2019	7
		Previous Work			
		Comparative study			
3	Chapter 3: System design	Design constraints & design methodology	9/20/2019	10/17/2019	27
		Engineering design standard			
		Theory and theoretical calculations			
		Product subsystems and selection of components			
		Manufacturing and assembly			
4	Chapter 4: System testing and analysis	Experimental Setup, Sensors and data	10/28/2019	11/3/2019	5
		Results, analysis and discussion			
5	Chapter 5: Project Management	Project plan	11/14/2019	11/20/2019	6
		Contribution of team members			
		Project execution monitoring			
		Challenges & decision			

		making			
		Project bill of material & budget			
6	Chapter 6: Project analysis	Life long learning	11/28/2019	11/30/2019	2
		Impact of engineering solution			
		Contemporary issues address			
7	Chapter 7: Conclusion and recommendation	Conclusion	12/3/2019	12/4/2019	1
		Future recommendation			
8	Design of prototype	Parabolic trough	10/15/2019	11/2/2019	17
		Vacuum box			
		Plastic sheet holder			
9	Parts Purchase	Wood	9/5/2019	10/24/2019	45
		Plastic sheet			
		Reflective material			
		Vacuum Pump			
10	Manufacturing	Vacuum Box	9/18/2019	10/1/2019	13
		Sheet holder			
11	Testing	Vacuum Pump	10/25/2019	12/4/2019	40
		Plastic sheet			

Table 5.1: Tasks and their duration

Task	**Assigned members**
Chapter 1: introduction	Saad, Yousif
Chapter 2: Literature Review	Abdulwahab, Abdulkarim
Chapter 3: System Design	ALL
Chapter 4: System Testing & Analysis	ALL
Chapter 5: Project Management	Abdulkarim, Saad
Chapter 6: Project Analysis	Abdulwahab, Yousif
Chapter 7: Conclusion & Recommendation	Saad
Design of Prototype	ALL
Parts Purchase	ALL
Manufacturing	Abdulwahab, Yousif
Testing	Abdulkarim, Saad

Table 5.2: Tasks and assigned members

Task	**Assigned**	**Contribution (each)**

5.2 Contribution of Team Members

A member or more were assigned to the following tasks in the table 5.3. The criteria depended on the ability and the time required to complete each task. In the table below we can see each task with its named members and their percentage of contribution.

Introduction		Saad, Yousif	50%
Chapter 2: Literature Review	Project Background	Abdulwahab, Abdulkarim	50%
	Previous Work		
	Comparative study		
Chapter 3: System design	Design constraints & design methodology	ALL	25%
	Engineering design standard		
	Theory and theoretical calculations		
	Product subsystems and selection of components		
	Manufacturing and assembly		
Chapter 4: System testing and analysis	Experimental Setup, Sensors and data	ALL	25%
	Results, analysis and discussion		
Chapter 5: Project Management	Project plan	Abdulkarim, Saad	50%
	Contribution of team members		
	Project execution monitoring		
	Challenges & decision making		
	Project bill of material & budget		
Chapter 6: Project analysis	Life long learning	Abdulwahab, Yousif	50%
	Impact of engineering solution		
	Contemporary issues address		
Chapter 7: Conclusion and recommendation	Conclusion	Saad	100%
	Future recommendation		
Design of prototype	Parabolic trough	ALL	25%

	Vacuum box		
	Plastic sheet holder		
Parts Purchase	Wood	ALL	25%
	Plastic sheet		
	Reflective material		
	Vacuum Pump		
Manufacturing	Vacuum Box	Aabdulwahab, Yousif	50%
	Sheet holder		
Testing	Vacuum Pump	Abdulkarim, Saad	50%

Table 5.3: Tasks & contribution of the members

5.3 Project Execution Monitoring

Meeting with the team members was essential for the completion of this project. These meetings were made weekly and biweekly, some times it was regular meeting and sometimes it would be a workshop meeting. In table 5.4 shows the list of meeting and other events for our project during fall semester 2019.

Date	**Events**
One time a week	Assessment class
Weekly	Meeting with group member
Biweekly	Meeting with Advisor
25 Oct, 2019	Finishing the prototype
14 Nov, 2019	Midterm presentation
23 Nov, 2019	First test of the system

29 Nov, 2019	Finishing the final prototype
3 Dec, 2019	Test the system
12 Dec, 2019	Final submission of the report
-- -- , 2019	Final presentation

Table 5.4: Dates of Activities & Events

5.4 Challenges and Decision Making

Challenges are inevitable when starting something new, and our project have a new and different Idea. Below will be listed the main challenges we had encountered.

1) Directing the solar rays

2) Selection of material

5.4.1: Directing the solar rays

In our project we rely heavily on the solar rays coming from the sun, we believe that we can manipulate these solar rays and benefit from them. By directing a lot of solar rays to one point (in our case one line) we will get a lot of energy concentrated into that line.

To do that we relied on the parabolic equation for the parabolic trough, and the focal point equation where we can direct solar rays to become concentrated onto one line. We place the plastic sheet directly on the focal point where the solar energy will be concentrated, that will provide enough heat to soften the sheet and then onward to forming into the desired shape.

5.4.2: Selection of material

We had to find the best plastic material that has a low melting point temp. it had to be a hard plastic and not foam, so it can serve it purpose, which will be product packaging and of that source.

We also had to find material that has great reflecting properties. We will place the reflective material on the upper side of the parabolic trough where the solar rays will be onward reflected to the plastic sheet that is placed on the focal point.

5.5 Project Bill of Materials and Budget

Table 5.5 shows the cost of the material we bought for the completion of this project. The cost is all listed in Saudi Riyals (SR).

Material	**Costs (SR)**
Wood	50
Plastic Sheets	30
Vacuum pump	400
Mold	20
Heater	150
Total	**650 SR**

Table 5.5: Cost of the materials

Chapter 6: Project analysis

6.1 Life-long learning

Undergoing the lifecycle of this project, enhanced the team’s soft and technical skills. We learned how to communicate ideas and insights professionally, report our finding clearly, and manage tight schedules parallelly. Most importantly, we learned how to work our differences aside by focusing on achieving the mission of the project. We have worked together and brain-stormed to multiple challenges we encountered during the execution of the project. Time management were important aspect that we’ve gained confidant.

6.1.1 Software skills

Throughout the period of the project, we maintained a repetitive visit to the lab to develop our collaboration in designing the animated parts of the thermoforming process in SolidWorks program. We explored our understating of the controlling systems when we conducted a site visit to a local commercial factory. Nevertheless, Microsoft Excel, Word and PowerPoint were handy to our necessities.

6.1.2 Hardware Skills

All the members of the group took part in constructing one important part of the project which is the vacuum box. To epitomize our resources, we used our mechanical advantage to design and take measures in order to build the part in the wood shop. Moreover, we exploited the carpenter large power tools while taking all the safety hazards into consideration by using the safety tools. These kinds of experiences grow the motives to build something by your own gained knowledge. Accordingly, Clear data and measurement were gatherrd and executed part were assembled.

6.1.3 Time Management Skills

To Start with a say by Abraham Lincoln "Give me six hours to chop down a tree and I will spend the first four sharpening the axe”. To make of most of our working hours useful we plan ahead before the meeting times start, to identify all the tasks needed to be done. We multitasked when the situation was needed and worked under a pressure. As a result, we produced more and were efficient at finishing the meeting tasks and goals. One rule helped us significantly is the Gantt chart. Deadlines are noted at the calendar with their tasks is a enormous pusher to do the work. A constant reminder to make us committed to the assignments. We also kept in touch with the advisors regularly.

6.1.4 Project Management Skills

Our group operated uniquely by assigning the work between us by the best area of expertise. Some of us were better than other in some parts. Nonetheless, we discuss the assignment tasks among each other and are by mutual consent. Afterward we go over the previous work and discuss the details where the one responsible explain and clarify to the other members his work and seek feedback to improve and progress. More, all ideas are heard and discussed before making choices.

6.2: Impact of Engineering Solution

The project mature our sense of the things around us and inspired us to think from more than point of view. This will give us an insight regarding the different aspect beside engineering. Most essentially, the additional value that engineers seek to satisfy. In the following , all the detailed impacts and there terms.

6.2.1 Society

In terms of society impact , we are honored to magnify awareness towards thermoforming process and how simple tools can achechve them . the project will help house holds who have an vacuum cleaner and other tools to make the exact mold that they wish to make. Moreover , cities residents must be aware of the different green resources that we can use such as the solar energy and Wind energy.

6.2.2 Economy

Thermoforming process may seem complicated or advanced process. However, with right tools and materials, everything is possible. In the beginning, we thought that we had order the parts from abroad but we researched for solutions and took our time to find the ultimate result which is to build it ourselves. After testing the materials, we concluded that we need more workable material. In the End the total money spent did not exceeded the 200 SAR and most of that goes to the fact that we used available recourses to our use.

6.2.3 Environmentally

The major impact of our project does not focus in this side . Nonetheless, there is a minimal reduction of polluting the earth. Whereas users won't need to use there fuel engine cars when they can produce their needs in home. Our ambition is to aware others about this process and its components.

6.3: Contemporary Issues Addressed

We can consider this part as an advantage for us because we do not have Contemporary Issues. Because we are depending heavily on clean energy, in other words our main source of energy is the sun, so we can say that our project is a environmental friendly project that uses small amount of electricity. In addition, all of our products can be recycled which consider as a huge advantage in this manner.

Conclusion:

In every work you do in your life you gain experience and new information that can benefit you in your normal life. During or project we went through a lot of challenges that made us improve our communication skills, critical thinking skills and we managed to work as a team. In addition, while working in the project we managed to achieve our main goals and results, which support and follow the 2030 vision. We proved that we can implement the concept of thermoplastic process by using limited sources of energy plus constructing simple designing plane and using simple parts that are in the hand of reach for every one. Based on engineering science, we used many engineering aspects such as heat transfer, manufacturing, designing and computer aided design. Those areas of engineering supported us and helped us and improved our background. In this project, we learned how to use various devices that are essential in our lives such as sensors, vacuum and heaters. In addition, we managed to improve our skills in engineering software such as solidworks. This project like any other projects it must have some challenges and problems. We faced a problem with converting the solar energy to electrical energy, so we disregard the idea of using clean energy and deepened on electrical energy.

Future recommendation:

Below is a list of important points should be taken in consideration for whom going to continue in our project:

- Clean energy: for students that desire to enhance and improve our project we recommend them to utilize green energy to be their main source of energy. Due to the shortage of time and focusing on other aspects in our project we did not manage to use the solar energy. However, now we made the concept behind our project very clear plus we selected the right formulas and the specifications for the whole project. Thus the next group just have to focus on the green energy part to fulfill the main goal of this project and follow the 2030 vision.

- Heater with bigger surface area: at this part having a heater with a larger surface area will give the ability to heat and cover bigger area of the plastic sheet. By achieving that we can use larger and complicated geometries of molds. Our heater had a small surface area so the next group must have a bigger heater to be able to produce various shapes.

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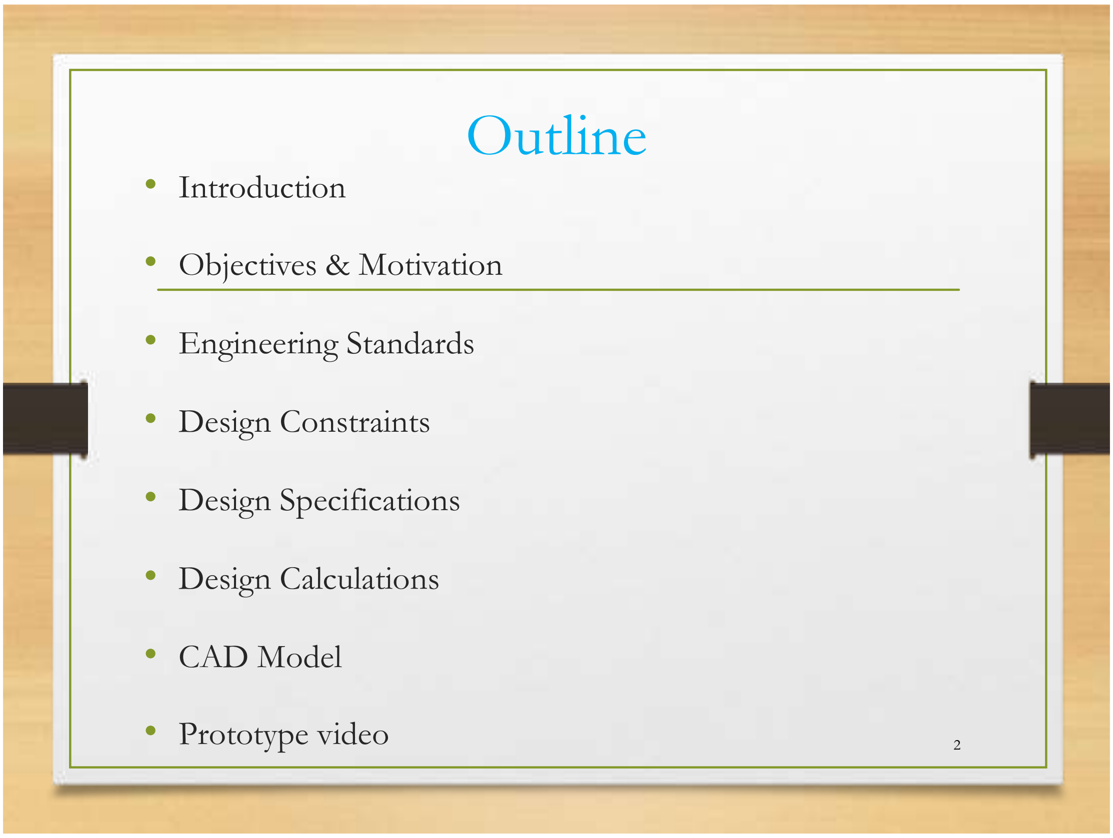
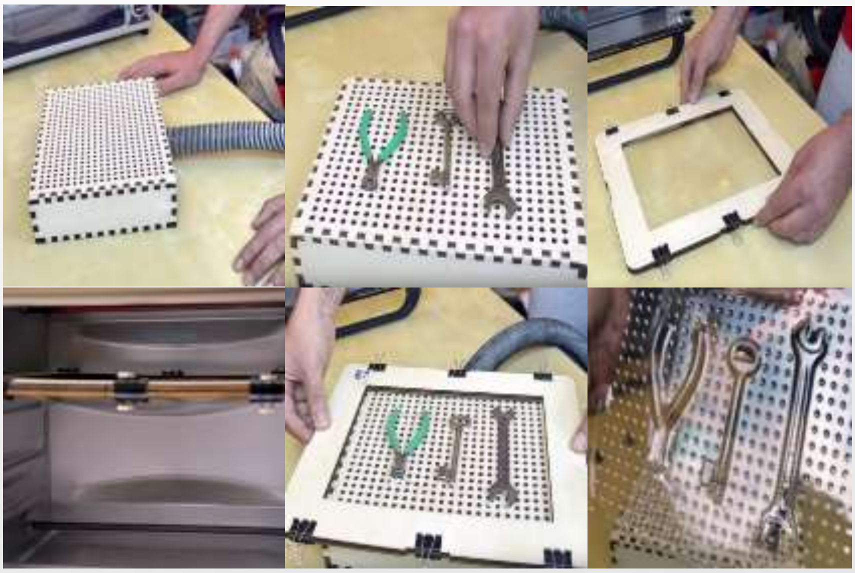
Final presentation:



Introduction

- Thermoforming is a manufacturing process where a plastic sheet is heated to a pliable forming temperature, formed to a specific shape in a mold.
- We will use solar energy to heat the plastic to it softening temperature. After heating the plastic we place it on a wooden box which is connected with a vacuum in order to suck the heated plastic.

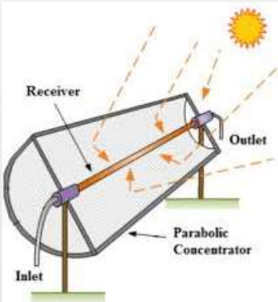
Introduction



Objectives & Motivation

- Design and development of thermoforming process relying on renewable energy resources to produce products.

- Harvest the solar energy
- Reduce cost.



Standards

- Plastic Sheet: ISO 13636:2012 – PET Film and sheet standard to thickness between 0.15-1.5mm
- Wooden Box: ISO 1096:2014 -- Plywood Standard
- Vacuum pump: Dry vacuum cleaners -- IEC 60312-1:2010 (MOD) + A1:2011 (MOD)

Design constrains

- Selection of materials.
- Mold size.
- Simple geometries.

Design specifications

Part	Dimensions
Vacuum box	40 cm x 30 cm, 8 cm height
•Plastic sheet PVC [Polyvinyl Chloride] (thermoplastic) *recyclable	Size: 210 x 297 mm Thickness: 0.2 mm Softening temperature: 80 C Melting Temp: 100 – 180 C
Vacuum machine	Pressure: -20kPa Voltage: 220 -240 V Power: 2300 W
Mold	Size:15 x 6 cm Thickness: 0.8 cm
Heater	Area covered: 0.0103m^2 Power: 32.73kJ Weight: 3 kg Voltage: 220V – 240V

Calculations

Heat Calculations:

- Q=mcΔT
- m=93.25g
- c=1170 ⁄ ∘
- Q=93.25x1170x(360-80)
- Q=32730.75J

Calculations

Time Calculation:

- Q=Pxt
- t = ⁄
- t = 32730.7 ⁄2300 /
- t = 14.238 s

Calculations

Calculation of heat transfer:

For Convection heat transfer we use Newton's Law of Cooling:

$= h A_s (T_s - T_\infty)$

h convection heat transfer coefficient, W/m2 · °C

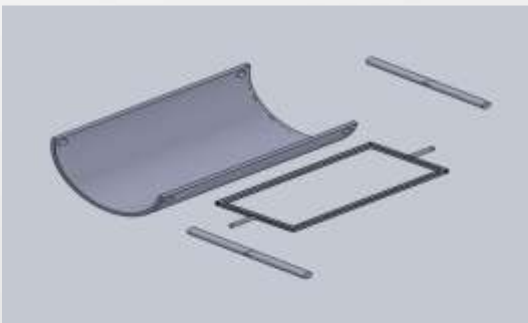
As the surface area through which convection heat transfer takes place

Ts the surface temperature

T∞ the temperature of the fluid sufficiently far from the surface

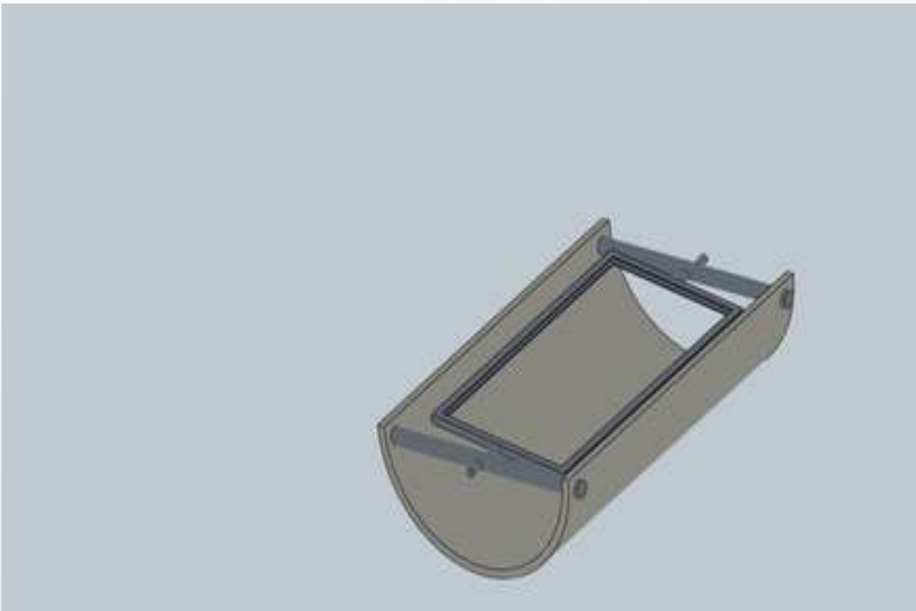
Calculations

- Calculation for heat transfer:
- For radiation heat transfer we use Stefan-Boltzmann law:
- $Q = \varepsilon \sigma A_s (T^4_s - T^4_\infty)$
- $\sigma = 5.670 \times 10^{-8} W/m^2 . K^4$
- " ε " A measure of how closely a surface approximate a blackbody.



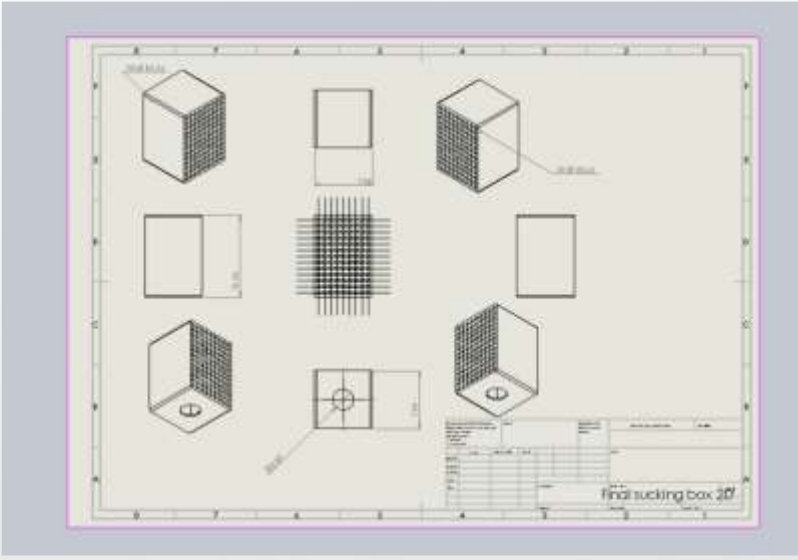
Calculations

- Calculation for heat transfer:
- And when combining convection and radiation heat transfer we get:
- $Q_{total} = Q_{conv} + Q_{rad}$
- $Q_{total} = h_{conv} A_s (T_s - T_\infty) + \varepsilon\sigma A_s (T_s^4 - T_\infty^4)$
- $Q_{total} = h_{combined} A_s (T_s - T_\infty)$
- $h_{combined} = h_{conv} + \varepsilon\sigma (T_s - T_\infty)(T_s^4 - T_\infty^4)$



Calculations

- Parabolic equation:
- $Y=nx\uparrow 2$
- To find the focal point for the parabolic trough:
- focal point$=1/n \div 4$



Thank you for listening

Prototype pictures: