FABRICATION AND EXPERIMENTAL STUDY OF A PROTOTYPE FOR DRYING AIR USING SOLAR TECHNOLOGY

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ABSTRACT

Siddique Leather Works (SLW) use thermal energy for heating air to dry leather by burning oil and coal. It is a high-priced method. This cost can be reduced significantly by incorporating solar energy in the process using Parabolic Trough Collectors (PTC). This system is feasible for installation in the industry and it meets the requirements quite conveniently. As solar energy is not available all the time, therefore a hybrid system consisting of the setup already present in the industry and PTC is preferable. It can provide the air at same temperature and conditions. A parabolic trough collector heats the air indirectly by using a carrier fluid. It focuses the sun rays on its focal line where a copper pipe is present containing oil. The oil is heated which in turn exchanges its heat with air in the heat exchanger. This air is blown at the desired conditions of flow rate and temperature. Based on the complete study and calculations, a PTC plant model has been proposed for SLW to fulfill their requirements.

PREFACE

It is a great opportunity for us to have the **Bachelor of Mechanical Engineering at SMME, NUST.** In the accomplishment of degree we are submitting a project report on "Fabrication and Experimental Study of Prototype for Drying Air Using Solar Energy". The project is supposed to be a solution of the industrial problem which was being faced by Siddique Leather Works (SLW).

Siddique Leather produces high quality leather with the annual capacity of 24 million square feet. Being such a big an renowned leather industry it also emphasizes on economical energy measures and eco-friendly behavior. It has decided to transform its leather drying processes from the old and traditional processes of fuel burning to the modern solar technology. We stepped up to propose the solution of the problem and developed a prototype which leads to the proposal of installing a large solar plant in SLW.

Subject to the limitation of time efforts and resources every possible attempt has been made to study the problem deeply and to propose an appropriate solution. The whole project is measured through the questionnaire, the data further analyzed and interpreted and the results were obtained.

ACKNOWLEDGMENTS

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We would also take this opportunity to express our gratitude and sincere thanks to Mr. Abdul Naeem Assistant Professor SMME, NUST for his valuable support.

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ABBREVIATIONS

SLW	Siddique Leather Works
PTC	Parabolic Trough Collector
LFC	Linear Fresnel Collector
DSS	Dish Sterling System
$\mathbf{h_c}$	Convective heat transfer Co-efficient
$\mathbf{h_r, p - c}$	Radiative heat transfer co-efficient between plate and cover
$\mathbf{h_r, c - a}$	Radiative heat transfer co-efficient between air and cover
T	Temperature
K	Thermal conductivity
V	Velocity
℃	Temperature in degree centigrade
$\mathbf{C_p}$	Specific heat at constant pressure
$\mathbf{Q_u}$	Useful heat gain
$\dot{\mathbf{m}}$	mass flow rate

CHAPTER 1

INTRODUCTION

The aim is to replace the traditional methods of leather drying by a more effective and cheap method. Currently, most of the leather industries are burning natural gas and oil to heat air for drying their leather. The problem is, these methods are not cost effective. They are depleting the limited energy resources of the country and they are polluting the environment too. So it will be a lot more beneficial if a system is designed which will replace these methods by using renewable energy sources. The most convenient of all the methods is to make use of solar energy to heat the air required for drying leather. As Pakistan has a lot of sun, so it is quite obvious that our newly designed system will be comparatively much cheaper and cost effective.

Solar energy is cheap being used worldwide to accomplish various energy demands to some extent. It will, therefore, provide us with an efficient method to dry leather in the industry, replacing the old and conservative methods.

To dry leather, temperature of the air must be at 45-55 °C at a specific flow rate. Making use of solar energy, there are different options to attain these goals. Various systems are being used and are very practical throughout the world. After the complete study of all the systems which make use of solar energy for heating purposes and keeping in mind the constraints and feasibility, the most suitable system based on the calculations and observations has been selected.

Using this method, a prototype has been built. Based on this prototype and calculations, an industrial model for SLW is proposed for the purpose of leather drying in a much efficient and modern way.

Parabolic troughs are used for collecting the energy from the sun. This energy is focused on the focal line of the PTC where a copper tube is present containing the oil. It raises the temperature of the oil. This heated oil then exchanges the heat with air in the heat exchanger, which is further used for drying leather. The oil then goes into the storage tank; a centrifugal pump sucks the oil from the tank and circulates it in the cycle, making it a close loop system.

This project is not only fruitful for leather industry but with proper modifications, it can be used in any industry fulfilling its thermal needs.

CHAPTER 2

LITERATURE REVIEW

2.1. Solar collectors

Solar thermal collector uses the sunlight for heating purposes. The collector is used for converting energy from solar radiations into a useful form .This energy reaches to the earth in the form of electromagnetic radiations lying between infrared and ultraviolet region. Different factors like climatic conditions, location and direction of the surface affect the solar energy reaching the earth, but approximately its intensity is 1000 watts per square meter on a clear sunny day.

2.1.1. Classification of Solar collectors

Solar collectors are classified into two categories

1. Non-concentrating collector
2. Concentrating collector

1) Non-concentrating collector

These collectors are used for domestic purposes and for space heating. These collectors have a specific area to face the solar radiation. Non-concentrating collectors are further classified into two categories

1. Flat plate collectors
2. Evacuated Tube Collectors

2) Concentrating Collector:

This collector collects the heat from the sun and concentrates on a point or a line due to which a high temperature is achieved. These collectors are generally used in industries for generating steam. They are also known as imaging collectors because they collect energy from the sun using curved shaped mirrors. The mirrors or the system is tilted towards the sun. A tracking system is attached with the concentrator which tracks the sun. The energy collected from the sun is used to heat the fluid which is flowing inside the tube. Then this hot fluid is used to heat the air or water in the heat exchanger. The types of concentrating collector are

1. Parabolic Trough Collectors(PTC)
2. Linear Fresnel Collectors(LFC)
3. Heliostats
4. Dish Sterling System(DSS)

2.1.2. Parabolic trough collectors:

In these collectors receiver tubes are positioned along the focal line of each parabolic mirror. PTC is usually made by the special mirror or stainless steel surfaces bent in a parabolic shape. The basic job of this collector is to focus the sunlight on the receiver tube passing through the center of trough. The fluid flowing into the tube gains heat from the sun via PTC. The temperature range and efficiency of the PTC depend upon the aperture area of trough. The main components of parabolic trough is shown in figure 2.1.

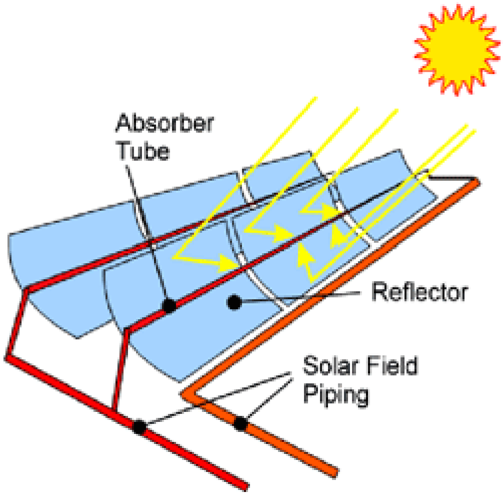


Figure2-1: Parabolic Trough [1]

Advantages of PTC:

- This is the most developed and commercially tested collector.
- It is used to produce steam.
- PTC produces steam with conventional steam that can be easily hybridized and fossil fuel can be used as supplementary fuel so that energy is produced even when the sun is not shining.
- Thermal oil, water or any molten salt can be used as a working fluid.
- It is cost effective and has high efficiency.

Disadvantage:

PTC does not produce working fluid temperature as high as some of other concentrating collectors.

2.1.3. Linear Fresnel Collector (LFC):

In LFC the receiver tubes are positioned above several mirrors those mirrors provides the greater mobility in tracking the sun. The further procedure is same as the PTC. It is called as linear concentrator. The LFC is shown in figure 2.2.

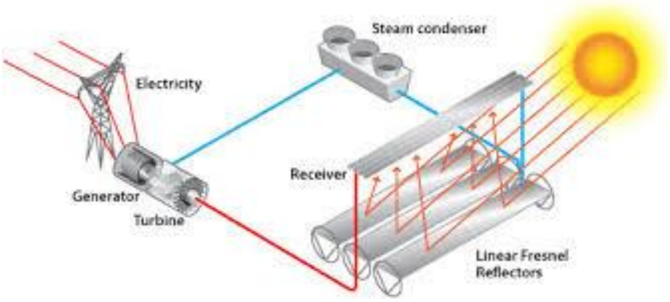


Figure2- 2: Linear Fresnel Collector[2]

Advantages OF LFC:

- Solar mirrors that are used in LFC are flat these mirrors are less expensive than the parabolic shaped mirror used in PTC.
- Absorber tube used in LFC is less expensive than that of PTC and simpler.
- There is no need of coupling for absorber tube.
- LFC can also hybridize with fossil fuel as PTC.

Disadvantages:

- It does not produce fluid temperature as high as the PTC.
- Its efficiency is lower than the PTC.

2.1.4. Heliostat:

Heliostat was invented by Willem's Grayesande. It is a device that usually uses plane mirrors to concentrate the sun light on a predetermined target. The target may be a far away from the heliostat or a direction in space or it might be a physical object. To concentrate light reflective surfaces of mirrors is kept perpendicular to the bisector of the angle between the direction of sun and the target. A heliostat is shown in figure 2.3.

Figure2-3: Heliostat[3]

Advantages of Heliostat:

- It is used for power production.
- It can be hybridized with fossil fuel so we can collect output when sun is not shinning.
- It produces the highest fluid temperature among all concentrating collectors.

Disadvantages of Heliostat:

- It is not commercially developed.
- It has low efficiency.

2.1.5. Dish Sterling System (DSS):

This system uses a mirrored dish to concentrate the sunlight. Keeping in mind the cost factor, many smaller sized flat mirrors are combined to form a dish type structure. It directs and concentrates solar rays on the receiver which absorb collect the heat and transfers it to the engine. The engine which is commonly used in dish system is Stirling engine. This system is used for power generation. The DSS is shown figure 2.4.

Figure2- 4: Dish Sterling System[4]

Advantages of Dish Sterling System:

- It has the highest efficiency among all the concentrating systems.
- It is used in power generation.
- It has a very minimal water requirement. It means no cooling water is required.

Disadvantage:

- Dish sterling system does not lend itself well for thermal energy storage.

Summary:

There are several methods by which can make use of solar energy for fruitful purposes. Solar collectors are the types of solar platforms used for different purposes. Keeping in view the needs and requirements, all the types of concentrating and non-concentrating solar collectors were studied. Based on the prior study of each case, a method can be selected which is best suited to fulfill the requirements.

CHAPTER 3

METHODOLOGY

A prototype has been built for solar air dryer using solar parabolic trough collector. Parabolic trough being the most important part of the system reflects all the sun rays incident upon it and focuses them on its focal line. A copper pipe is fitted on its focal line in which oil flows, which is used as a heat transfer fluid. Hence all the rays are focused on the copper tube and are used to raise the temperature of oil flowing in it. Now the oil flows into the heat exchanger. Here the oil is made to exchange heat with the air blown by a fan attached to it. In the prototype, a compact heat exchanger has been used for the purpose. The oil which has now transferred the heat with the air will move towards the oil tank, which is used to store the oil. Oil pump sucks this oil from the oil tank and pumps it to the copper tube again. This cycle goes on, heating the air as long as the system is running.

3.1. Selection of a method:

3.1.1. Why a few of the systems are dropped?

- Other concentrated systems are very expensive.
- They were not readily available in Pakistan.
- They require more maintenance as compared to the parabolic trough collectors.
- Some of the other systems like solar air collectors are not too efficient to be used.

3.1.2. Selected systems for air heating

The two methods selected are:

1. Solar Air Collector
2. Parabolic trough Collector

3.2. Solar Air Collectors

Solar air collectors directly heat the air from sun rays that can be used in industry. This is the simplest method of heating air from the sun and it is much cheaper than any other method. It does not require any medium in between sun and air, it directly heats the air. Maximum of 55 degree centigrade can be achieved using this method.

During calculations, Area of the solar air collectors required to fulfill the requirements came out to be too large to be installed in the industry. It was not feasible for the industry so it had to be ruled out. Area required was $1159.51m^2$.

3.3. Parabolic Trough Collectors:

In parabolic trough collectors, a parabolic shaped mirror heats the oil which is used as a carrier fluid. That hot oil, in turn, exchanges the heat to the air. The area required by these troughs was significantly less as compared to the solar air collectors.

Properties of PTC [5]

1. Operating temperature up to 500 degree centigrade
2. Concentration Factor C=20-70
3. Typical Power Size 50 to 400 MW
4. Commercial projects commissioned
5. Annual Efficiency 12% to 14 %
6. Heat Transfer Fluid
    - Thermal Oil
    - Water
    - Molten Salt.

Their temperature range is 50ºC-450ºC and has high collector efficiency depending upon the collecting area (aperture area). Main working Principle of PTC is that it requires direct normal irradiation (DNI). The sunlight is reflected and focused by the parabolic mirror on the absorber tube which heats up the heat transfer fluid.

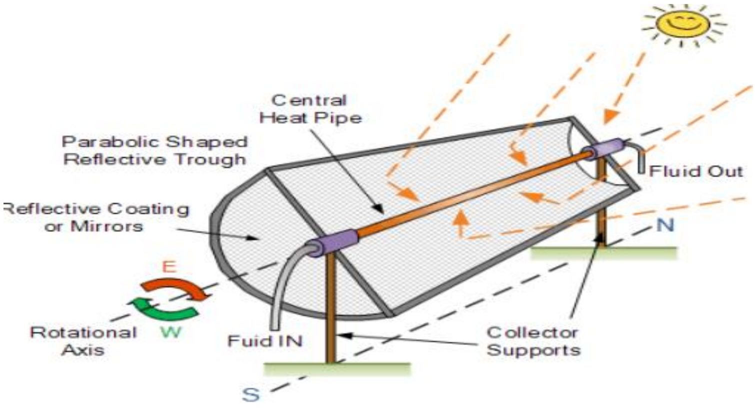


Figure3-1: Main Components of Parabolic Trough Collector[5]

There are five main components of this system:

1. Parabolic trough
2. Copper tube
3. Heat exchanger
4. Storage tank
5. Oil pump

3.3.1. Parabolic trough

Parabolic trough solar collector is made by a parabolic shaped concentrator, as shown by its name. It reflects and focuses sun radiations at a receiver tube positioned at the focal line of the parabolic trough. The receiver uses the incoming radiations, converts them into thermal energy and transfers it to the fluid medium flowing within the receiver tube. This method of concentrated solar collection has the benefit of higher efficiency and lower cost as compared to other methods, which could also help for thermal energy gathering, for producing electricity or for both.Therefore it is an important way to exploit solar energy directly.

A highly polished stainless steel sheet of grade 304(26SwG) is used as a reflecting surface. It has the reflectance of about 0.80. Depending on the reflecting area a very high temperature can be attained. Stainless steel used as a reflecting material improves temperature but is not adequate for the steam generation. It can be replaced by some other material like mirrors and aluminum foils[6].

The concentration ratio of parabolic trough is actually the ratio between collector aperture area and the total area of the absorber tube shown in equation. Its value mostly lies between

20 and 70. It actually represents the reflector quality. A higher concentration ratio allows the collector to reach higher temperature with minimum losses[7].

$$C=\frac{W}{\pi D_o}$$

$\mathrm{D_o} = \text{Externel diameter of receiever tube}$

W= Width of parabolic trough

The Parabolic Trough Solar Collectors system will certainly play an important role to provide well-organized, cost-effective and environment friendly energy supply around the world in next 5-10 years [8].

For the fabrication of prototype, the parabolic trough installed at solar park of NUST has been utilized.

Figure3-2: Parabolic trough installed at NUST Solar Park

3.3.2. Copper tube:

It is a crucial part of the system as it has to carry the hot oil which will in turn exchange the heat to the air. Copper tube is attached to the parabolic trough and is present on its focal line. PTC focuses the sun rays on this tube and oil is heated in it. In the prototype developed, its diameter is 1 inch. Stainless steel tube can also be used according to the requirements. Using evacuated tube can increase the efficiency by reducing heat loss.

The copper tube should be at its focal line so that it can get maximum heat from the sun. It intakes the oil from one end and ejects it from the other. The circulation is made by a pump which makes the heat exchanging possible.

The pipes that connect the copper tube, pump and heat exchanger should be properly insulated by vacuum especially in winters so that external air does not interfere with the fluid.

While transferring heat there are three types of losses

1. Convection
2. Conduction
3. Radiation

The main loss is due to convection because of external temperature and wind velocity. These factors affect the tubing significantly. The other loss is by conduction through the bracket that hold joint to the stand of parabolic trough and pump itself. The third loss is by radiation which is due to the reflection of sun rays by parabolic trough. Therefore, efficiency of no parabolic trough can reach up to 100 percent.

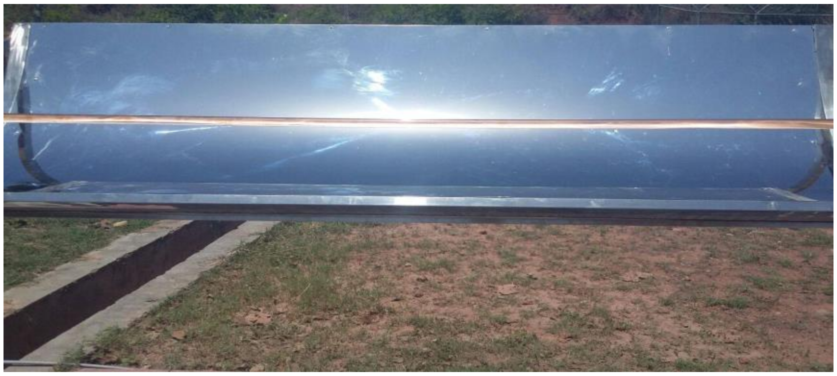


Figure3-3: Copper tube at its full focus

3.3.3. Heat exchanger:

Heat exchangers are devices that facilitate the exchange of heat between two fluids that are at different temperature while keeping them from mixing with each other.

In this prototype model, the heat exchanger used has 37 cuboid coils; each has a thickness of 0.3cm, width of 1.3cm and a length of 35.56cm.

Compact type heat exchanger[9] is selected for the purpose, as this type of exchangers are specifically designed to realize a large heat transfer surface area per unit area per unit volume. The ratio of heat transfer surface area of a heat exchanger to its volume is called the area density β. The value of β for the compact heat exchangers are usually greater than 700 m^2/m^3.

In this model, car radiator is used as compact heat exchanger as it was easily available, had all the properties required and it was economical too.

Figure3-4: Compact heat exchanger used. (Car radiator)

3.3.4. Storage Tank

Oil storage was the key aspect a system for which an oil tank has been fabricated. It has one inlet and one outlet, on the opposite sides. Oil is charged in from the opening present on the top surface to be circulated in the cycle.

While flowing in the cycle, oil leaves the heat exchanger and enters the tank from its inlet. After leaving the tank through its outlet, it enters into the pump that circulates the oil.

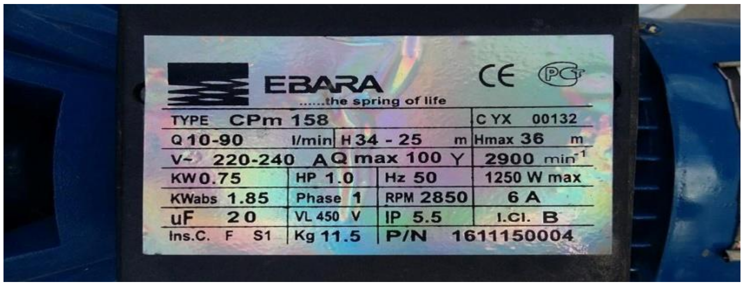
It can store 10 liters of oil at a time.

Figure3-5: Oil Tank

3.3.5. Oil Pump:

An oil pump is used to circulate the oil in whole structure. The main issue to deal with while selecting the pump was the high temperature of oil. One has to be quite specific for the selection of pump as ordinary pumps operate for the maximum of 70 degree centigrade but here temperature can increase up to 200 degree centigrade. So an oil pump of 1 horsepower was selected. It has ceramics seal in it and has a mass flow rate of 90L/minute.

Some of the properties are shown..



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uF 20	VL 450 V	IP 5.5	I.Cl. B
Ins.C. F S1	Kg 11.5	P/N 1611150004	

Figure3-6: Pump Properties

It receives oil from the storage tank and outlet is attached to the parabolic trough collector. Teflon hydraulics pipes are used to connect the copper tube with the pump and also with the heat exchanger in order to minimize the heat loss and due to its high temperature bearing capacity.

The pump used is shown in the picture below.

Figure3-7: Oil Pump

This system achieves the temperature of the air above 45 degree centigrade quite conveniently.

Summary:

A lot of methods are being used on prototype as well as industrial scale for thermal energy generation. The requirements were highly specific as air was to be heated at least 45 degree centigrade which in turn can be used to dry leather at a specific flow rate and the method used was required to be feasible and also economical on industrial scale. Based on the requirements, the list was cut short to two main methods i.e. Solar Air Collectors and Parabolic Trough Collector method. Thorough and complete calculations for both of the methods were performed and finally PTC came out to be the best possible method. PTC is relatively feasible and economical. This method uses heat exchanger, copper tube, pump, parabolic trough and storage tank as its main components.

CHAPTER 4

CALCULATIONS AND RESULTS

4.1. Calculation for total heat required to produce required air flow:

Diameter of fan = 2 feet =0.6096m

Radius of fan = 0.3048m

Area = $\pi(radius)^2$

= 3.14$(0.3048)^2$

Area= 0.2917m^2

$$\dot{m} = \rho A V$$

= (1.1455)(0.2971)(10)

$$\dot{m} = 3.3414\ kg/s$$

$$\mathrm{Q_u} = \dot{m} c_p \Delta T$$

$$\mathrm{Q_u} = 3.314 * 1.005 * 15$$

$$\mathrm{Q_u} = 49.958 KW$$

For 8 fans total energy required = $\mathrm{Q_u} * 8$

=$67.134 KW * 8$

=399.66KW

$$\text{Area required} = \frac{399.66}{0.34488}$$

Area required = 1159.51 m^2

4.2. Calculation for theoretical heat gain from Solar Air Collector and PTC:

Table4-1: Temperature and intensity observation at different hours of the day

Time	Oil temperature (℃)	Cover temperature (℃)	Air Temperature(℃)	Ambient Temperature(℃)	Intensity (W/m^2)
10:00 am	33	55	47	30	765
10:30 am	38	70	48	32	980
11:00 am	52	72	49	32	999
11:30 am	49	77	51	35	1002
12:00 pm	53	73	50	34	994
12:30 pm	50	70	48	33	972
01:00 pm	49	67	48	32	900
01:30 pm	50	62	47.5	32	845
02:00 pm	47	59	47	31	740
02:30 pm	47	56	46	30	693
03:00 pm	42	51	46	30	650

4.3. Theoretical heat gain from Solar air collector:

Glass transmissibility = 0.8235 [10]

Tilt angle = 45°

Mean plate temperature = 140°C [11]

Wind heat transfer co-efficient = h_w= 9.5 W/$m^2 k$

Ambient Air temperature = 25℃

Absorbance $\alpha(\theta)$ of black plate = 0.867

$\tau(\theta).\sigma(\theta)$ = (0.835)(0.867)= 0.72

Average wind speed = 1 m/s

Plate to cover spacing= 15mm

Emittance of anodized aluminum=$\varepsilon_p = 0.82$ [10]

Single glass cover emittance = ϵ_c=0.88 [10]

$$h_r, p - c = \frac{\sigma\left({T_p}^2 + {T_c}^2\right) + (T_p + T_c)}{\frac{1}{\varepsilon_p} + \frac{1}{\varepsilon_c} - 1} \quad [12]$$

$$h_r\text{,c-a} = \varepsilon_c \sigma({T_c}^2 + {T_a}^2)(T_c + T_a) \quad [12]$$

$$\text{Ra} = \frac{g\beta' \Delta T L^3}{v\alpha} \quad [12]$$

Nu=$1+1.44[1-\frac{1708(\sin 1.8\beta)^{1.6}}{Ra\cos\beta}][1-\frac{1708}{Ra\cos\beta}]^{+}+[\left(\frac{Racos\beta}{5830}\right)^{\frac{1}{3}}-1]^{+}$ [12]

Convective heat transfer Co-efficient=$h_c, p-c$ = NU$\frac{K}{L}$ [12]

$U_T=[\frac{1}{h_r,p-c+h_r,p-c}+\frac{1}{h_r,\mathrm{c-a}+h_w}]^{-1}$ [12]

$\mathrm{Q_i}=\mathrm{I}(\tau\sigma)$ [13]

$\mathrm{Q_o}=U_T(T_c-T_a)$ [13]

$\mathrm{Q_u}=\mathrm{Q_i}-\mathrm{Q_o}$ [13]

4.4. Theoretical heat gain from PTC:

Theoretical useful heat gain per unit area=$Q_A=F_R[I-\frac{A_{externel}}{A_{ap}}Ul(T_{fi}-T_a)]$ [14]

Heat removal factor=$F_R=\frac{\dot{m}C_p}{A_{in}Ul}[1-\exp(-\frac{A_{in}UlF'}{\dot{m}C_p})]$ [14]

Collector efficiency factor=$F'=\frac{\frac{1}{Ul}}{\frac{1}{Ul}+\frac{D_o}{h_{c-0}D_i}+\frac{D_o}{2k}*\ln(\frac{D_0}{D_i})}$ [14]

Total heat loss co-efficient = Ul =$h_{r,r-a}+h_w$ [14]

Convective heat transfer co-efficient of air =$h_w=\frac{Nu_aK_a}{D_o}$ [12]

Heat loss between tube and air through radiation=$h_{r,r-a}=\epsilon\sigma(T_r-T_a)({T_r}^2+{T_a}^2)$ [14]

$Re_{air}=\frac{\rho VD_o}{\mu}$ [12]

$Nu_a = 0.3Re^{0.6}$ [12]

Prandtl number=Pr $= \frac{C_p * \mu}{k}$ [12]

Heat transfer co-efficient between tube and oil=$h_{c-0} = \frac{k_o}{D_i}[3.6 + \frac{.0668(\frac{D_i}{L})Re_{oil}Pr}{1+0.04[\left(\frac{D_i}{L}\right)Re_{oil}Pr]^{\frac{2}{3}}}]$ [14]

Length of Parabola = 2.1m

Width of parabola=1.016m

Outer diameter of copper tube= D_o=2.54cm

Inner diameter of copper tube= D_i=1.778cm

Wind velocity = 1.2 m/s

Emissivity co-efficient of copper tube=0.07 [12]

Area of receiver tube = πD_oL= 3.14*0.254*2.1=0.167m^2

Aperture area of receiver= (W-D_o)*L [14]

= (1.016-0.0254)*2.1

=2.08m^2

Inner area of tube= $\frac{\pi {D_i}^2}{4}$=$\frac{3.14*0.1778*.01778}{4}$=0.000248$m^2$

Table4-2: Comparative Analysis of heat gain between solar air collector and PTC

Time	Theoretical Heat Gain from Solar air collector per meter square area(W)	Theoretical Heat Gain from PTC per meter square area(kW)	Intensity (W/m^2)
10:00 am	305.28	613.539	765
10:30 am	460.08	778.293	980
11:00 am	473.76	768.55	999
11:30 am	475.92	813.65	1002
12:00 pm	470.16	814.5235	994
12:30 pm	454.32	782.03	972
01:00 pm	402.48	721.2375	900
01:30 pm	362.88	672.66	845
02:00 pm	287.28	587.79	740
02:30 pm	253.44	547.4	693
03:00 pm	222.48	519.1	650

4.5. Experimental calculation for useful heat Gain from PTC:

Experimental useful heat gain = $Q_u = \dot{m}C_p\Delta T$ [14]

$Q_u = \dot{m}C_p(T_{oil} - T_a)$

$\dot{m} = mass\ flow\ rate\ of\ oil$

$C_p = specific\ heat\ of\ oil$

$T_{oil} = outlet\ temperature\ of\ oil$

$T_a = Ambient\ temperature$

Table4-3: Properties of air at different temperature

Time	**Reynolds number of air**	**Nusselt number**	$\boldsymbol{H_w(W/m^2K)}$	$\boldsymbol{H_{r,r-a}}$**(W/m²K)**	$\boldsymbol{H_{c-o}(W/m^2K)}$
10:00am	1779.134	26.74	28.8455	0.000389	365.07
10:30am	1703.576	26.05	28.8018	0.000893	369.81
11:00am	16994.887	25.98	28.8	0.000986	379.90
11:30am	1660.939	25.66	28.75	0.001193	376.32
12:00pm	1665.148	25.7	28.81	0.001004	374.08
12:30pm	1699.209	26.01	28.79	0.00088	372.72
01:00pm	1716.188	26.17	28.81	0.000716	371.06
01:30pm	1738.75	26.37	28.83	0.00058	368.72
02:00pm	1756.59	26.54	28.86	0.000494	367.39
02:30pm	1774.60	26.7	28.87	0.000416	365.61
03:00pm	1797.4	20.9	28.88	0.000292	362.86

Table4-4: Properties of oil at different temperature

Time	**Reynolds number of oil**	**Prandtl number of oil**	$\boldsymbol{F'}$	$\boldsymbol{F_R}$
10:00am	3843.672	315.29	0.8993	0.8992
10:30am	6024.002	204.3	0.8954	0.8951
11:00am	6414.87	192.8	0.8997	0.8936
11:30am	7427.1	172.7	0.8972	0.8966
12:00pm	6590.045	192.7	0.8965	0.8960
12:30pm	6023.325	209.3	0.8962	0.8958
01:00pm	5495.65	227.32	0.8957	0.8953
01:30pm	4749.16	260	0.8951	0.8946
02:00pm	4333.02	283.19	0.8947	0.8935
02:30pm	3967.57	306.31	0.8941	0.8938
03:00pm	3406.63	351.92	0.8937	0.8914

Table4-5: Experimental heat Gain from PTC

Time	Useful Heat gain Experimental(kW)	Intensity (W/m^2)
10:00 am	71.871	765
10:30 am	114.546	980
11:00 am	121.319	999
11:30 am	129.338	1002
12:00 pm	118.648	994
12:30 pm	111.531	972
01:00 pm	104.526	900
01:30 pm	88.198	845
02:00 pm	81.537	740
02:30 pm	74.988	693
03:00 pm	59.59	650

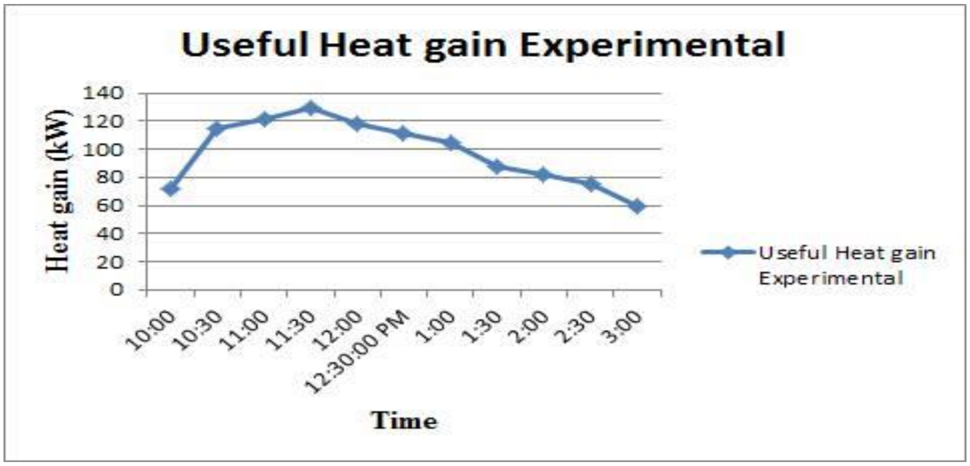

Figure4-1: Experimental Useful Heat Gain versus Time

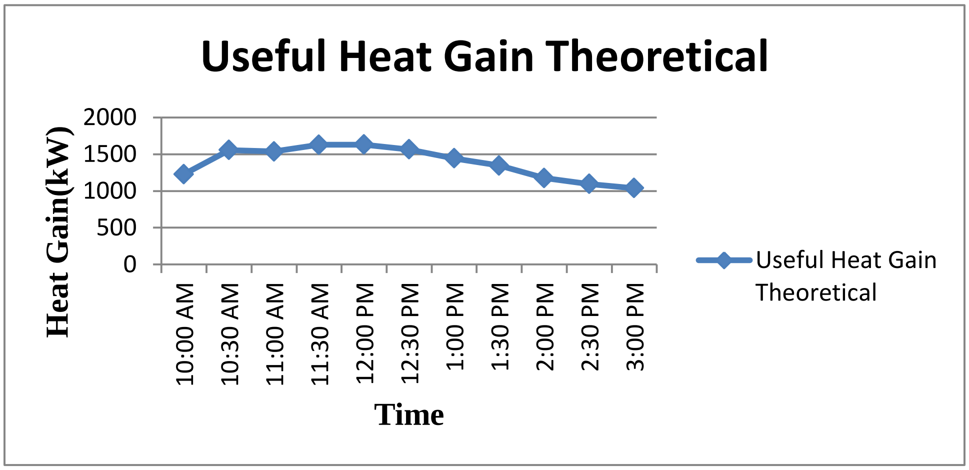

Figure4-2: Theoretical Heat Gain versus Time

4.6. Experimental and theoretical useful heat Gain from heat exchanger:

Experimental useful heat gain = $Q_u = \dot{m}C_p\Delta T$ [14]

$$Q_u = \dot{m}C_p(T_{air} - T_a)$$

$$\dot{m} = mass\ flow\ rate\ of\ air$$

$$C_p = specific\ heat\ of\ air$$

$$T_{air} = outlet\ temperature\ of\ air$$

$$T_a = Ambient\ temperature$$

Diameter of fan = 13inches =0.3302m

Radius of fan = 0.1651m

Area = $\pi(radius)^2$

= 3.14$(0.1651)^2$

Area= 0.0855m^2

$$\dot{m} = \rho AV$$

= (1.1455)(0.0855)(2.6)

$$\dot{m} = 0.254\ kg/s$$

Heat gain from oil=$\mathrm{Q_{u,oil}} = \dot{\mathrm{m}}\mathrm{C_p}\Delta\mathrm{T}$

$$\mathrm{Q_{u,oil}} = \dot{\mathrm{m}}\mathrm{C_p}(\mathrm{T_{th,air}} - \mathrm{T_a})$$

$$T_{th,air} = \frac{Q_u}{\dot{\mathrm{m}}\mathrm{C_p}} + \mathrm{T_a}$$

Theoretical heat gain from air = $Q_u = \dot{m}\mathrm{C_p}(\mathrm{T_{th,air}} - \mathrm{T_a})$

Table4-6: Useful Heat Gain from heat exchanger

Time	Useful Heat gain Experimental(kW)	Useful Heat gain theoretical(kW)
10:00 am	4.354	71.871
10:30 am	4.098	114.546
11:00 am	4.335	121.319
11:30 am	4.1	129.338
12:00 pm	4.1	118.648
12:30 pm	4.335	111.531
01:00 pm	4.098	104.526
01:30 pm	3.97	88.198
02:00 pm	4.098	81.537
02:30 pm	4.097	74.988
03:00 pm	4.353	59.59

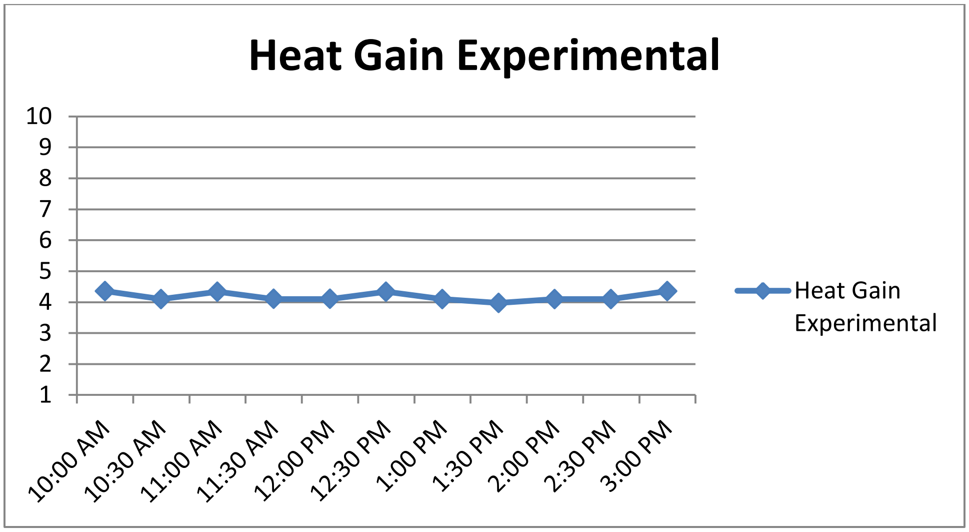

Figure4-3: Experimental heat gain versus Time (heat exchanger)

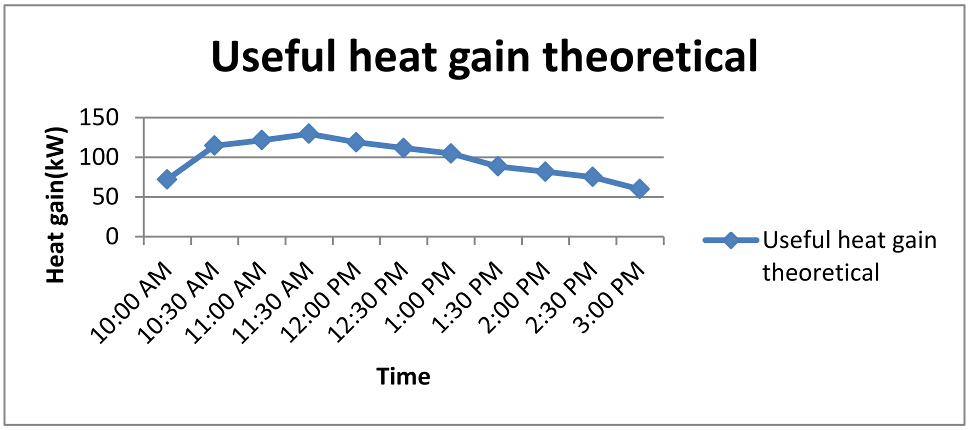

Figure4-4: Theoretical heat gain versus Time (heat exchanger)

CONCLUSIONS

Total amount of heat required=399.96kW

Amount of heat exchanged by 0.4239 m2= 4.345kW

Area of heat exchanger required for the industry=$39m^2$

Total number of parabolic trough collectors required for the industry=92

RECOMMENDATIONS

Subject to the limitation of time efforts and resources every possible attempt has been made to study the problem deeply and to propose an appropriate solution. The whole project is measured through the questionnaire, the data further analyzed and interpreted and the result was obtained.

Still a lot of space is present in the project in where improvements can be brought and more can be obtained from the same prototype. Recommendations made for the further improvements are:

Improvement in Copper Pipe:

The copper tube used at the focal length of the parabolic trough was not in its best condition. It was rusted and had not been used for almost a year or so. It was not in its best working condition. Due to lack of resources, it couldn’t be replaced. Replacement of this tube will definitely help the prototype to raise its standards.

Insulation:

The Teflon pipes and the steel pipe between pump and the heat exchanger were not insulated which was also a result of limitation of resources. It caused a lot of heat to lose decreasing the efficiency of the system. Insulating the pipes and copper tube properly will help a lot in obtaining better results. Proper Insulation of heat exchanger can also be required.

Control system:

The temperature of the air can also be controlled using PID or a microcontroller attached to a thermocouple which will help keeping the temperature within the range of 45 to 55 degree centigrade after sensing the temperature. An air mixer with valves can also be installed. Now if the temperature rises above 45 degree centigrade, the controller will cause a mixing of the air in the box by allowing the cold air in it. As a result, it will drop the temperature of the air back to 45 degree centigrade.

Powering fan via solar energy:

The fan can be made to run by solar energy using photovoltaic cells. As it doesn’t require much power to run it can easily be shifted on solar energy. The photovoltaic cell available in NUST Solar Park was not in a perfect condition to experiment on.

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