Experimental Investigation of High Performance Moderate Vacuum Solar Flat Plate Collector

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Abstract: **This research paper represents the experimental investigation and analysis of a flat plate collector which incorporates a moderate vacuum enclosure within the system. Flat plate collector with vacuum environment within the system provides various benefits as compared to ordinary collectors such as outstanding thermal characteristics, supreme optical features, highly versatile and also has a capability to provide pure energy which is efficient for basic household, industrial process and space heating application. This paper mainly emphasis on the design of the evacuated collector model in which a absorber plate (0.4 *0.3m) made of copper material which is entirely enclosed by vacuum layer that is installed within the system with supporting inlet and outlet ports for fluid circulation and the temperatures were calibrated at set intervals depending upon the constant mass flow rate. It demonstrated that with the help of employing magnets to create a strong repulsive force between the glazing and absorber surface the designed enclosure was successfully sustained by the overall imposed vacuum pressure and stresses The paper will also explore the various challenges, expectation, requirements and application of the collector model along with the brief discussion of the vacuum evacuated concept which is taken into concern.**

I. INTRODUCTION

Energy is the basic need for all characteristics of human life, infact it is accounted as the livewire of all sectors such as industrial, agricultural, transportation, shipping etc. Energy is considered as one of the most crucial constituent in building the socio economic and economic growth. Hence for safe and rapid economic growth, it is the nation's responsibility to adopt a valuable consideration for the development, improvement and secure adoption of the energy resources in order to meet the excessive energy demand of consumers. In today's advanced globe, to encounter with the drastic consumers energy demand the reliance on non-renewable resources such as petrol, oil, coal, natural gas has reached to about 84% of overall energy demand which eventually causing to increase the cost of energy besides raising the environmental concerns. While on the contrary the renewable resources such as geothermal, solar, hydro and biomass accounts for just 13.5% and 6.5% approximately which is extremely low. The ultimate resolution for the above issue is the extensive execution and utilization of the renewable energy sources in every sector of our routine life.

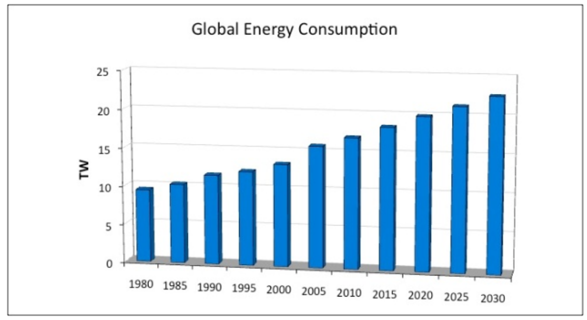


Figure 1: Increasing trend of global energy consumption

The above figure (1) clearly shows that there will be a rapid growth in the consumption of the energy over the entire globe in the upcoming future which causes a significant rise in energy demand. This increasing energy consumption trend ultimately aware of the exhaustion of the fossil fuels in the future and will cause to a substantial peak rise in demand for the non – conventional energy resources. This increasing trend distinctly states that an extensive research and well planned long term strategies should be created, maintained and adopted in order to cope up with the future energy demand as a result to ensure a proper energy balance across globe. The non-renewable sources are easily available, inexhaustible, immense amount and environmentally friendly. The extensive usage of these resources in day to day life will definitely prove to be the promising alternative in satisfying the peak increasing consumers demand furthermore will also tackle different issues such as global warming, environmental concerns, human health, price fluctuations etc. One of the promising nonrenewable energy sources is known as solar energy. Each and every life on the earth is ultimately reliant on the energy which is created by sun. Sun is known as the most substantial heat generator because no other heat sources produced by human being can compete against it. Every year, the sun energy gained by the earth is around 15000 which are far greater than the energy produced by power sector across entire globe. Therefore the fact is only a tiny amount of solar energy is utilized by the world for fulfilling the needs of mankind. Enhancing the use of wide scale pure, cost effective and never ending solar energy will certainly results in building the nation's security, suppressing the pollution and most significantly will boost sustainability. A substantial proportion of energy demand of consumer can be achieved by employing the solar energy for heating water coupled with the help of a flat plate collector.

Solar collector works on the principle of capturing the incident solar radiation and converting the radiation into heat. Generally the solar collectors are classified into two types: Concentrating and Non Concentrating type. The main difference between these two types of collector is depended upon the absorber area (the area which absorbs the solar radiation) and the aperture area (the area on which the solar radiation is intercepted). The aperture area in case of non-concentrating type is same as that of area of absorber while on the other hand in concentrating type, aperture area is greater than that of area of absorber. For low temperature application (less than 100℃ c) the non-concentrating type specifically flat plate solar collectors are employed, while for higher temperature application (more than 100℃) concentrating type solar collector are taken into consideration.

Flat Plate Collector:

A Flat plate solar collector is basically a type of heat exchanger which uses a concept of trapping the solar radiation and then converting the trapped incident solar radiation into heat. This converted heat is generally used for different application such as household, industrial process heat, building integration etc. In this type of collector system the incident flux varies from 1000W/m^2 and the wavelength from 0.3 to 3μm .

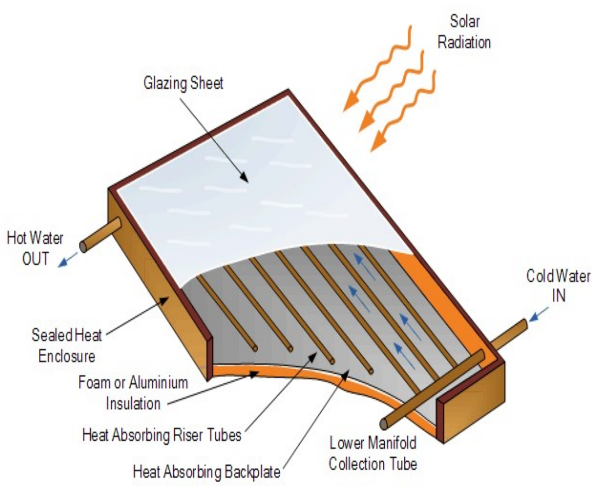


Figure 2: Configuration of solar flat Plate collector

II. LITERATURE REVIEW

A) Absorber Plate: The basic function of the absorber plate is to absorb the maximum possible radiation transmitted through the glass cover (glazing) and simultaneously it should reflect minimum towards the upward atmosphere and backward to the collector chamber. Later this maximum possible heat gain by the absorber plate should be used to heat the working fluid flowing through the circulating tubes.

Material colour	Absorbance (α)
White	0.07
Fresh snow	0.13
White enamel	0.35
Green paint	0.50
Red brick	0.55
Grey paint	0.75
Black tar	0.93
Flat black	0.98
Granite	0.55

Table 1: Absorber plate color coating and its absorbance intensity

Physical Properties: A comparison of several physical characteristics of aluminum and Copper are given below in the table:

Physical property	Copper	Aluminium
resistivity, Ω-mm^2/m	0.016642	0.03
mass density, kg/dm^3	8.89	2.7
expansion coefficient, µm/(m °C)	16.7	23.86
thermal conductivity, W/(m K)	398	210

Table 2: Comparison of physical properties between copper and aluminum

As we can see from the above table it clearly shows that the physical properties of copper material are higher and superior compared to the aluminum. For instance, if we take a look at the thermal conductivity of both the material it states that the copper has high heat conducting capacity due to its high thermal conductivity which indicates as one of the most positive factor for the application of copper material instead of aluminum . However, copper has high thermal conductivity also it has low expansion coefficient which helps it to prevent the expansion of material under increasing temperature. Besides copper is considered as one of the best electric conductor which is able to transmit the phonon and free electrons under vibration.

Tensile Strength:

Strength of the material is one of the most important properties which is extensively used and recognized. While undertaking any type of material for specific application, the property of tensile strength of that particular material plays a dominant role. The capability to sustain the forces in the form of pulling or stretching is termed as tensile strength of the material. It is generally calculated by the amount of force it resists before its breakage. However tensile strength of the copper material is more (the largest stress the component can sustain along its length without subjected to tearing failure) as compared to aluminum; although the strength of materials is increased if the materials are alloyed.

CHARACTERISTICS	COPPER	ALUMINUM
Tensile strength (lb/in^2).	55,000	25,000
Tensile strength for same conductivity (lb).	55,000	40,000
Weight for same conductivity (lb).	100	48
Cross section for same conductivity (C.M.).	100	160
Specific resistance (W/mil ft).	10.6	17

Table 3: Comparison of Characteristics between copper and aluminum (5)

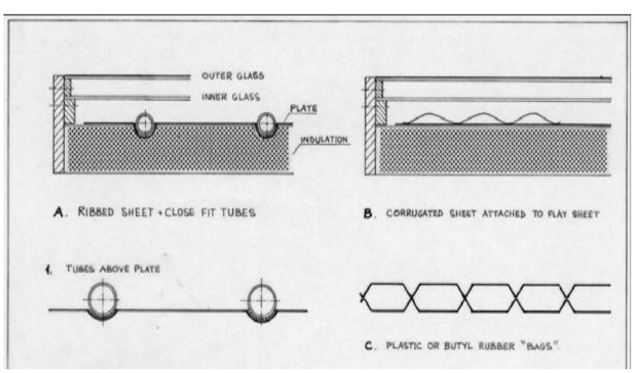
Thermal Conductivity

Thermal conductivity is the measurement of the capability of conducting heat of the metal. This characteristic differs for various types of material and is termed as the most crucial consideration in the application where higher temperature is desired. In case of flat plate collector, to enhance the efficiency attaining of higher temperature is must. Copper and aluminum are the two main materials which are generally used in collector system for absorber plate due to its high rated conductance. As copper is the superior conductor of heat, it's beneficial to employ this type of material in case of heat sinks, heat exchangers etc.

Thermal Expansion

Thermal expansion is termed as the ability of the matter to change in volume with regards to change in temperature across heat transfer. This characteristic is generally measured in terms of its thermal expansion coefficient which is described as change in fractional length of matter for fractional change in degree of temperature. As in article (6), the thermal expansion coefficient of copper is 16.7 which is lower than the aluminum 23.86 .In other words, the thermal expansion coefficient for copper is 35% less than that of aluminum because of the destructive force acting in between the joints and enlarged sag (7). However copper proved to be the most promising material to be employed in case of solar flat plate collector due to its lower thermal coefficient of expansion.

Configuration of the Absorber Plate:



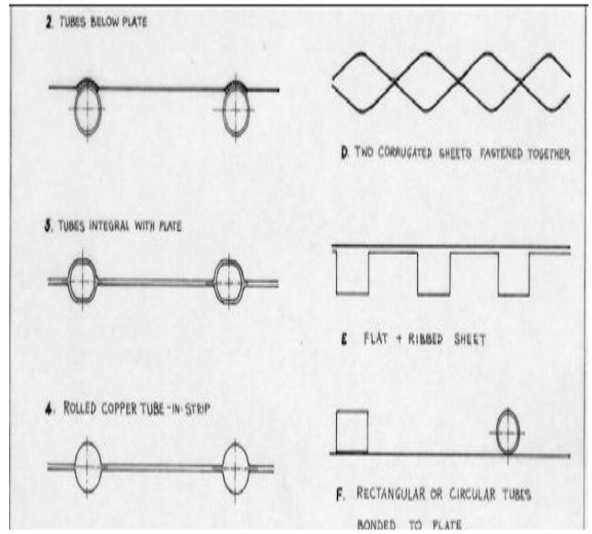


Figure 4: Different types of pipe and absorber plate configuration (3)

B) Thermal Losses:

Conduction, Convection and Radiation are the three modes of heat transfer by which usually the generation of heat losses initiates. Conduction is termed as the process of heat transfer through a solid material. In a solar flat plate collector, generally the heat transfer by conduction medium is developed at the absorber plate, side and rear end of the collector. Convection is termed as the process of heat transfer through the fluids such as air or liquid. In solar collector the convection heat transfer takes place because of the free convection to the ambient air (11). Generally the convection heat losses are found at the gap between the absorber plate and glass cover. However the convection losses can be suppressed by reducing the gap among them. Radiation is the transfer of energy with the help of electromagnetic waves that are emerged within the system due to temperature of the system. The total radiation from an impeccable dark body is relative to the fourth power of the absolute temperature of the body (11). In a collector system, the radiation loss basically takes place at the absorber plate because of the temperature of the plate.

Therefore, the overall thermal loss is given by an equation below,

$$Q_{therm} = Q_{conduction} + Q_{convection} + Q_{radiation}$$

Where, $Q_{conduction} = KA\,(T - T_a)$

$$Q_{convection} = h\,A\,(T - T_a)$$

$$Q_{radiation} = A\,F\,\sigma\,T^4$$

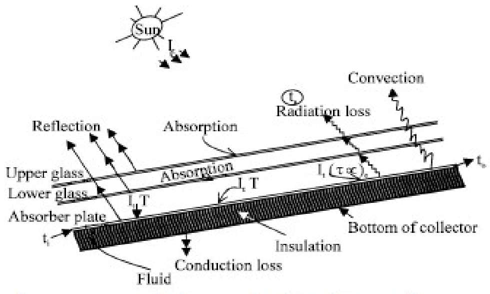


Figure5: Overall heat losses in a Solar Flat Plate Collector (12)}

Effect of wind velocity relative to loss coefficient:

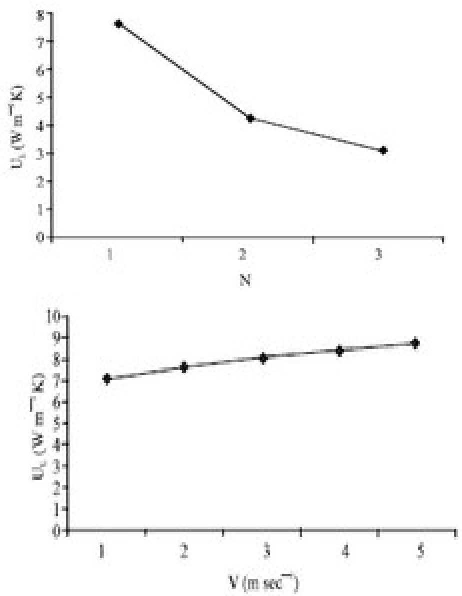


Figure 6: Speed V/s heat loss coefficient (12)

The above graph by S. N Agbo and E.C. Okoroigwe (2007) (12) demonstrates that the velocity of wind has a significant amount of effect on the heat loss coefficient. As we can clearly see from the above graph, as the wind velocity increases it ultimately causes to increase the loss coefficient. Therefore, the design of the collector system should be such that it should withstand and less affected by the wind speed.

Effect of tilt angle (β) relative to loss coefficient:

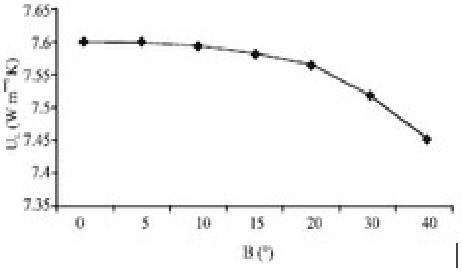


Figure 7: Tilt angle V/s heat loss coefficient (12)

Figure (7) represents the graph of effect of tilt angle on the heat loss coefficient. The graphs depicts that the varying tilt angle between the ranges of (0 to 40 degrees) causes insignificant effect on the loss coefficient, however the loss coefficient factor progressively decrease for increased tilt angles. As per research by **(Duffie and Beckman, 1947) (12)** have described about the tilt angle in flat plate collector located nearby to the equator will not be having remarkable effect with regards to the heat loss.

Effect of air gap on loss coefficient:

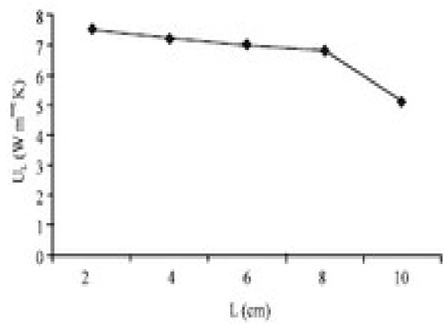


Figure 9: Gap span V/s heat loss coefficient (12)

The above graph shows the effect of varying air gap between the absorber plate and glass cover on the collector overall heat loss coefficient. It can be seen clearly that the loss coefficient decreases with increases in value of air gap. However, increasing the air gap promotes the heat losses through convection from absorber plate to glass cover. Therefore, it is necessary to optimize this air gap as a result to suppress convection. For an efficient system performance a suitable gap width of more than or equal to 5cm is usually preferred (Agbo 2006) (13).

C) Selective Absorber Coating:

Selective coating on the absorber plate is the most important feature which enables to increase the thermal performance of the heat plate in a flat plate collector system. Usually spray painting technique is used as the coating purpose besides electro type plating is also preferred as an alternative method. A surface which has high absorption capacity basically acts has a better heat radiator and has high Radivative emittance. In general 96% of the solar radiation absorbed by the flat black paint will also has a drawback of reradiating the most of the energy in the form of heat depending upon the glazing and absorber plate temperature. Ideally, the surface which is to be selected must have the property of absorbing the entire solar radiation and emitting none of it ($\alpha = 1$ and $\epsilon = 0$), as a result maximum heat could be transmitted to the working fluid..

Selective Coatings	α	ε	α/ε
Black Chrome	0.93	0.10	9.3
Black Nickel on polished nickel	0.92	0.11	8.4
Black Nickel on galvanized iron	0.89	0.12	7.4
Cu on nickel	0.81	0.17	4.7
Co3O4 on silver	0.90	0.27	3.3
Cu on aluminium	0.93	0.11	8.5
Cu on anodized aluminu	0.85	0.11	7.7
Black Chrome	0.93	0.10	9.3
Black Nickel on polished nickel	0.92	0.11	8.4

Table 4: Different selective coating properties

D) Piping

The appropriate configuration of piping plays an important role in solar flat plate collector for determining the mass flow rate of the working fluid. The material normally used for the pipes is copper which has high thermal conductivity as a result which maintains the high heating of the fluid besides there should be a proper insulation attached throughout the pipes to avoid the heat loss taking place. There are basically two types of configuration available in flat plat collector system namely the parallel and the serpentine type.

Parallel Configuration

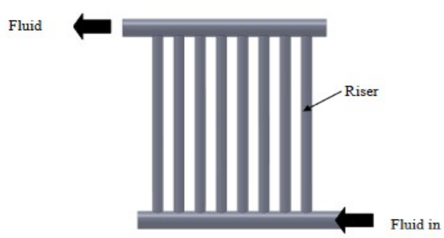


Figure 9: Parallel configuration (4).

Serpentine Configuration

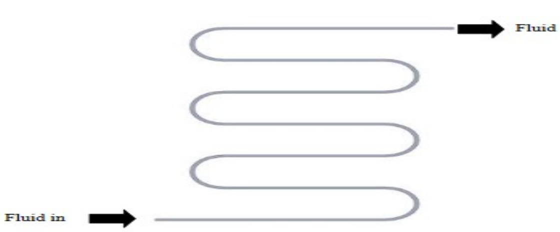


Figure 10: Serpentine configuration (4)

By comparing both the configuration, parallel type with headers pipes attachment at the top and bottom of the piping will discard the imbalance in the flow and maintain a uniform flow rate besides enhancing the efficiency of the solar flat plate collector. As per construction view, the parallel type proves to be more reliable as the joints used in this type can be easily assembled and disassembled together. Furthermore coming to the material of the piping, copper is the best suitable material due to its high thermal conductivity and can be welded easily on the other hand aluminum is bit harder for welding together.

E) Glazing

The main application of glazing is to transfer the short wavelength radiation received from the sun and to terminate the long wavelength originating from the absorber plate. Glazing also plays an important role in suppressing the convection heat losses from the top of the absorber plate. Glass is most commonly used as the material for glazing purpose because of its most favorable property of transmitting 90% incoming short wavelength radiation and blocking the reradiated long wavelength radiation from the absorber plate.

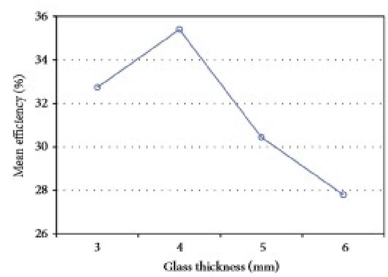


Figure 11: Glass thickness V/s Mean efficiency (14)

III. METHODOLOGY

This chapter will describe the overall methodology planned under this dissertation. It consist of 3 section out of which one section consist of overall design of solar flat plate collector such as design of pipes configuration and design of absorber plate using CATIA V5 R19 mechanical aided software while the second section consist of the overall constructional procedure of solar flat plate collector and the third section consist of experimental procedure .

3.1 Design Modelling of Solar Flat Plate Collector:

CATIA V5 R19

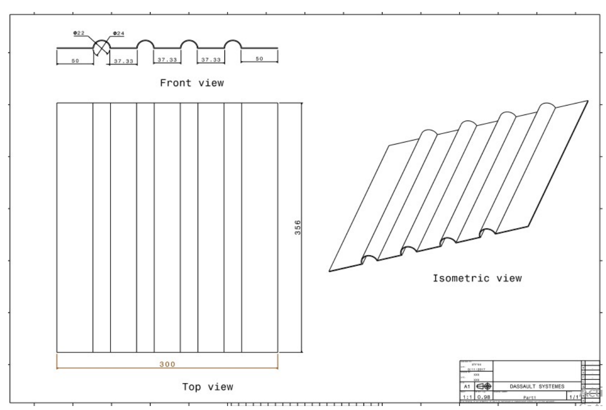


Figure 12: CAD Model Design of Solar Absorber Plate

Description of the absorber plate CAD model

The above CAD drawing shows the design configuration of the absorber plate in which several views such as front, top and isometric views are depicted with appropriate dimensions. As per the designed configuration the absorber plate was constructed by copper material due to copper having various efficient properties as discussed in the literature review. As per the design configuration the dimension of the absorber plate was chosen as length 356mm and width as 300mm while the internal and external diameter being 22 and 24mm respectively. Here the internal diameter taken as 22mm because of the pipe configuration on which the absorber plate is clamped while the external diameter taken as 24mm due to considering the thickness of 10mm. The thickness of the absorber plate was taken as 10mm because of the previous research undertaken regarding the varying plate thickness affecting the efficiency of the system mentioned in the above literature review. The fin spacing between the two consecutive external diameters on the absorber plate was maintained as 37.33mm which was ultimately depended on the pipe configuration as a result to ensure a proper replication of plate on the pipes while on the other hand an extended fin width of 50mm at the ends on both sides of the absorber plate was maintained with a view to enhance the collector efficiency by generating more heat due to extended absorber area. Here the overall length of the absorber plate only accommodates the riser pipes and not the manifold pipes due to which the absorber total length being less as compared to designed pipe configuration. The procedure of drawing this design in CATIA software was easy and contains just a few steps such as initially drawing 4 semicircles of required dimension with proper line spacing between them followed by extruding the constraint dimension to the required length.

CAD model design of pipe configuration

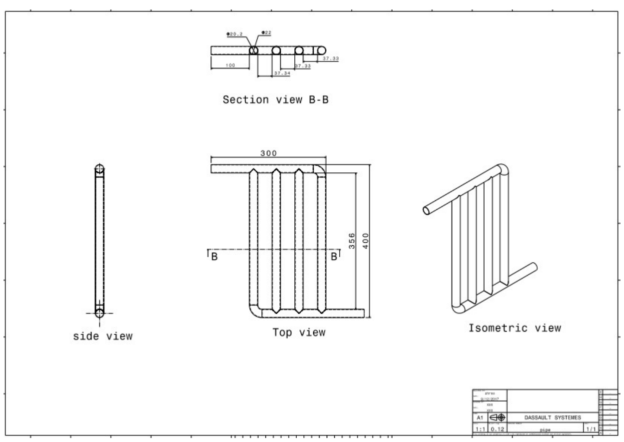


Figure 13: CAD Model Design of Solar Pipe Configuration

The above shown CAD drawing of the pipe configuration was designed and modeled by using the Catia software. As per the extensive research undertaken in the literature review regarding the different piping configuration, therefore a parallel type of configuration proved to be more efficient due to better flow rate of the fluid so this type of configuration was chosen and implemented in solar flat plate collector system. Figure (13) depicts different views such as top, side, section and isometric view with appropriate dimensioning of the parallel pipe type configuration in which 4 equally spaced riser pipes are connected together with the help of two header pipes that are basically used for flowing the fluid from inlet to outlet.

Actual 3D view design of absorber Plate

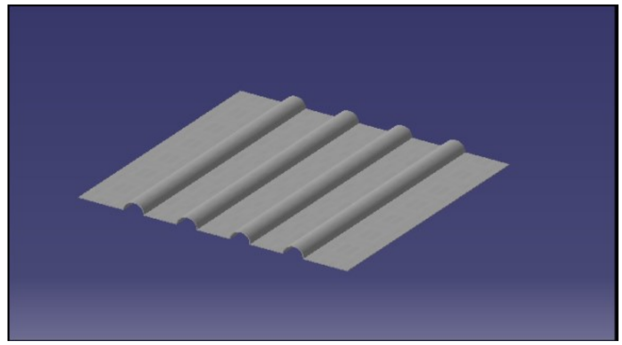


Figure 14: 3D view of absorber Plate

Actual 3D view design of Pipe Configuration

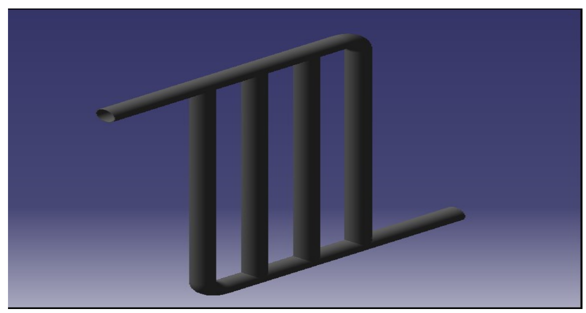


Figure 15: 3D view of pipe configuration

3.2 Constructional Procedure of the Collector:

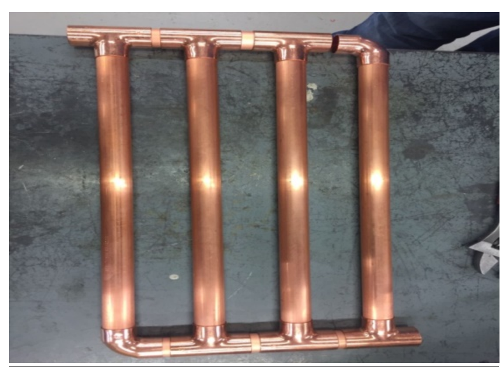


Figure 16: Joining of riser pipes with joints

The above figure shows the manual joining of riser pipes with the help of elbow and T joints while an appropraiate spacing between them is incorporated as per the design criteria

Soldering Technique

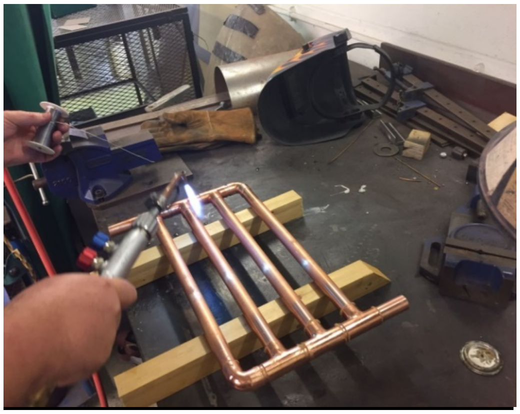


Figure 17: Soldering Process

Assembling of Aborber plate

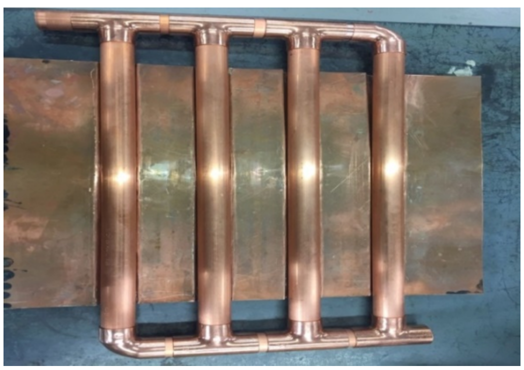


Figure 18: Assembly of absorber plate on pipe configuration.

Surface coating and Magnets Pasting on the absorber plate

Figure 19: Surface coating and magnet pasting process

A surface coating of black paint was sprayed on the absorber plate due to its extraordinary absorbtivity feature as discussed in the above literature review and after applying the paint it was allowed to dry in atmosphere for 30 min. After the completion of drying time, a 75*10*3 mm thick neodymium magnet each having capacity of 12.4 kg pull was pasted with the help of extra strong glue on the absorber plate as shown in the figure. Total 12 magnets were pasted, 6 on the top of the absorber plate and 6 on the interior side of the glazing, all of which were facing the same poles to each other with a view to create a strong repulsive force among them as a result to withstand the high vacuum pressure

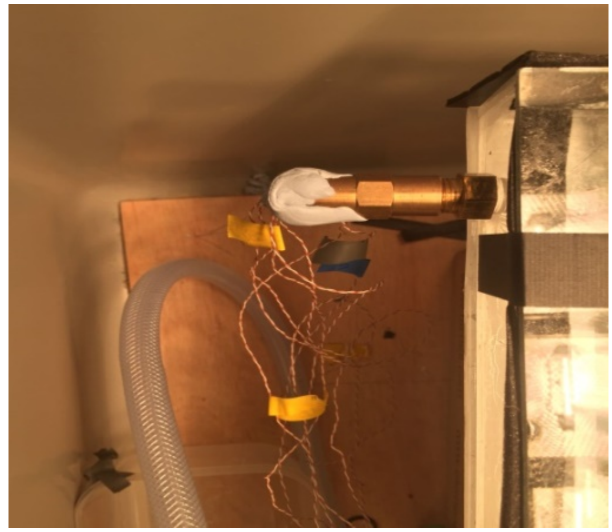


Figure 20: Vacuum port fitting

Final Experimental Setup of Flat Plate Collector Unit

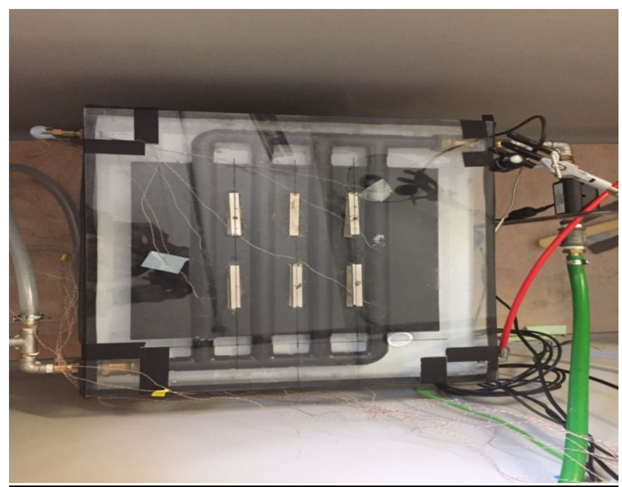


Figure21: Overall setup of flat plate collector

As we can see from the above figure, after necessary pipe fitting arrangement the thermocouples were inserted at the inlet and outlet port and also attached on the surface of the absorber plate. Overall 11 thermocouples were used in this collector system for calibration of temperature which will be discussed in detail in next chapter. Further a toughened glass of 3mm thick was selected for glazing purpose and was placed on the collector system. To maintain a vacuum tight proof environment inside the collector chamber, adhesive foam was applied at the edges of both the casing as well as glass cover as a result to ensure a no vacuum leakage takes place. In addition a thick layer of blutack sealant which basically acts as a pressure sensitive adhesive was applied at all the ports so as to maintain the vacuum pressure within the collector chamber. Finally as an alternative of Sun energy source an arrangement of 3 halogen bulbs each constituting 500watts was made as a power source which were totally focused on the glazing of the collector system. A pyrometer device with suitable stand arrangement as depicted in the above figure was made and utilized in order to calculate the amount of energy falling on the collector area.

IV. EXPERIMENTAL APPARATUS

The two main apparatus which were used in experimentation of flat plate collector are NI 9213 Module and a pyranometer.

1) NI 9213 Module:

It is basically a high density 16 channel input module which is intended for measuring the higher channel count system. By using this module, we can plug the thermocouples into the slots provided and collect the data in the form of tempratures through the LabVIEW. This module incorporates several features such as identification of open- thermcouple, anti-aliasing filters, high extend range of voltage mode, noise restitive and cold junction compensation (17).

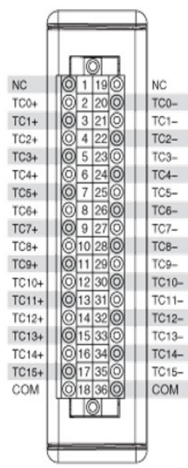


Figure 22: NI9213 Module

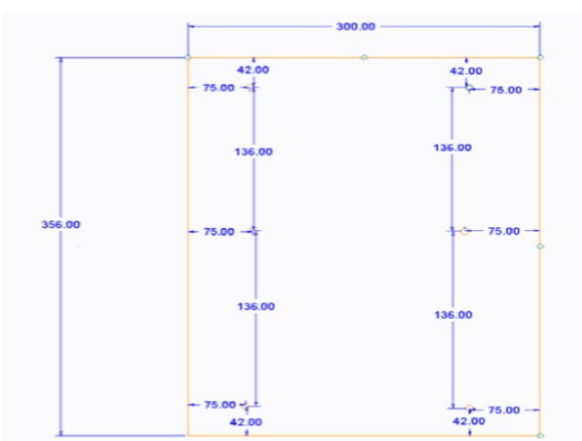


Figure23: Thermocouple Arrangement

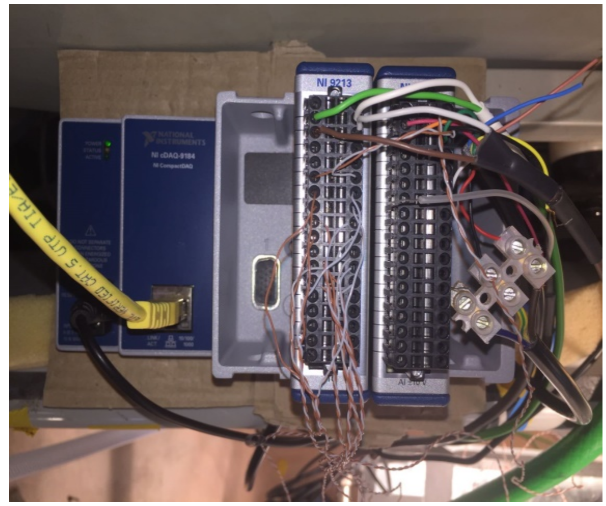


Figure 24: Thermocouple connection

The above figure (24) shows the schematic diagram of setup of thermocouples . Here overall 10 thermocouples are used in the present collector sysem, out of which 6 'K' type of themocouples are attached on the absorbe plate with appropriate designed spacing between them as depicted in above diagram therfore thery are , 1 'K' type attached to glazing to read the glass temperature. 1 'K' type is exposed to atmosphere to record the ambient temperature and 2 'T' type stainless steel thermocuples are connected to both the inlet and outlet port as a result to calibrate the fluid incoming and outgoing temperature. The ends of all of this thermocouples are plugged into the solts of the NI9213 module as shown in fgure ()which in turn provides the data in regards to temperature of each and every thermocouple which is connected with the help of the Labview Software.

Sr.no	Part	Thermocouple type	Thermocouple Number
1	Absorber Plate	'K'	T4,T5,T6,T7,T8,T9
2	Glazing	'K'	T10
3	Atmosphere	'K'	T11
4	Inlet, Outlet Port	'T'	T0,T1

Table5: Thermocouple type and its sequential number

2) Pyranometer:

The sun's radiation on earth's surface is specifically known as the overall radiation over a wavelength span of 280 to 4000nm which is an shortwave radiaton. Global shortwave radiataion is defined as the radiation which are incident on the surface that are horizontal in nature consisiting of overall sun's radiation, direct ,diffused and beam radiation. Pyranometers are generally the instruments which acts as a sensor to calibrate the radiation of shortwave length type (18).\

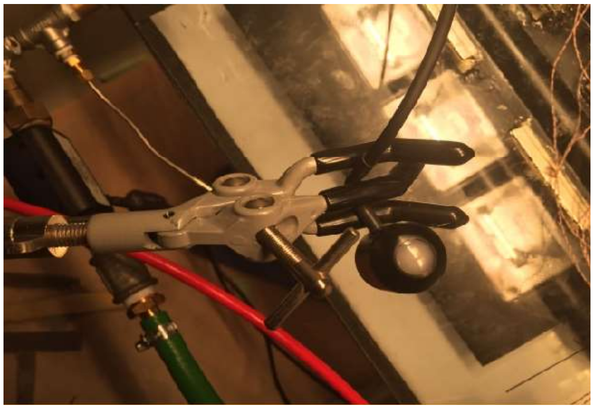


Figure 25: Setup of Silicon cell pyranometer

In our present collector system, a apogee SP-110 self powered pyranometer model with suitable stand arrangement was used to calculate the overall incoming radiation from the halogen bulbs which tends to incident on the glazing surface area. This instrument essentially consist of a diffuser known as filter, a photodiode, signal processing unit and a cable which was connected to the NI9213 module for measuring the intensity of radiaton as shown in figure.

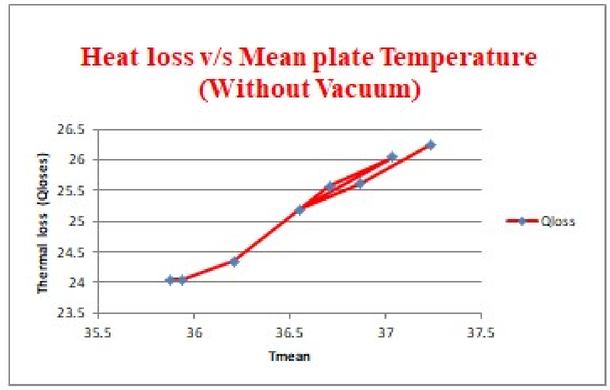
4. Experimental Results: (Without Vacuum)

4.2 Experimental Results: (Without Vacuum)

Sr No.	Time (min)	Tin (°C)	Tout (°C)	Tmean	Ta	Cp of water (J/g °C)	Mass flow rate (kg/sec)
1	10	19.24002	20.60452	35.87406	20.83675	4190	0.034
2	20	19.26514	20.62108	35.93951	20.90676	4190	0.034
3	30	19.23764	20.7019	36.20634	20.98237	4190	0.034
4	40	19.25816	20.85452	36.71142	20.72506	4190	0.034
5	50	19.22321	20.96889	37.03727	20.75942	4190	0.034
6	60	19.28272	20.82247	36.54998	20.79846	4190	0.034
7	70	19.24187	20.94863	36.86488	20.85865	4190	0.034
8	80	19.23919	21.11458	37.2422	20.82629	4190	0.034

Ac (m^2)	Power (W/m^2)	S (W)	U_L (W/m^2K)	Q_{loss}(W)	Q_{useful} (W)	Efficiency
0.2	1498.586	299.752	8	24.05969	194.387	0.129714
0.2	1386.132	277.2264	8	24.0524	193.167	0.139357
0.2	1472.319	294.4638	8	24.35834	208.598	0.14168
0.2	1453.44	290.688	8	25.57817	227.417	0.156468
0.2	1468.215	293.643	8	26.04457	248.689	0.169382
0.2	1463.969	292.7938	8	25.20243	219.353	0.14984
0.2	1360.686	272.1372	8	25.60997	243.145	0.178693
0.2	1477.244	295.4488	8	26.26546	267.168	0.180856

Table 6: Experimental results of flat plate collector without vacuum enclosures



The above graph depicts the heat losses versus mean absorber plate temperature of the solar flat plate collector without employing vacuum pressure within it. As we can clearly see from the graph, the increase in plate temperature caused to increase the thermal losses significantly. Initially the thermal losses raised to a significant level but in the middle zone the trend decreased for a while causing in decrease of the heat losses but at the final zone time the thermal losses attained to a peak level..

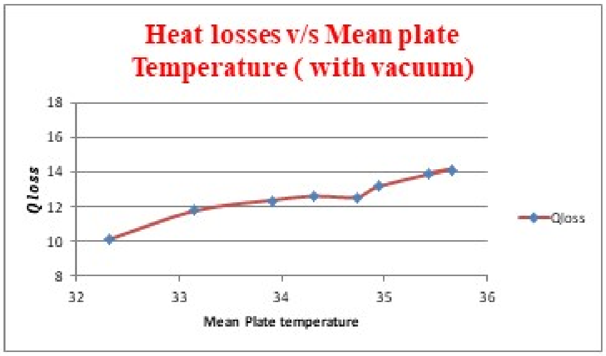
With vacuum:

With vacuum:

Sr No.	Time (min)	Tin (°C)	Tout (°C)	Tmean	Ta	Cp of water (J/kg °C)	mass flow rate (kg/sec)
1	10	19.06231	20.7977	32.31496	21.77156	4190	0.034
2	20	19.232	21.07692	33.14511	20.88557	4190	0.034
3	30	19.64997	21.85608	33.8993	21.00641	4190	0.034
4	40	19.67511	22.44636	34.32222	21.17587	4190	0.034
5	50	19.95232	23.15886	34.73263	21.65882	4190	0.034
6	60	19.92927	23.42381	34.94209	21.22673	4190	0.034
7	70	20.18294	24.50558	35.65061	20.88768	4190	0.034
8	80	20.10939	25.55216	35.42665	20.88396	4190	0.034

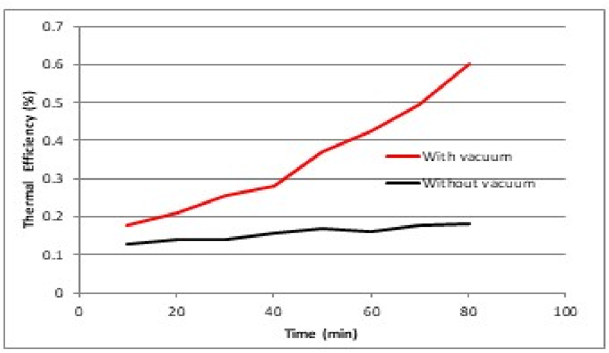
Ac (m^2)	Power (W/m^2)	S (W)	U_L (W/m^2K)	Q_{loss} (W)	Q_{useful} (W)	Efficiency
0.2	1394.34	278.868	8	16.86943	247.2232	0.177305
0.2	1254.798	250.9596	8	19.61527	262.8281	0.209458
0.2	1229.352	245.8704	8	20.62863	314.2818	0.255648
0.2	1402.548	280.5097	8	21.03415	394.7928	0.281482
0.2	1235.919	247.1838	8	20.91809	456.8031	0.369606
0.2	1178.46	235.6921	8	21.94458	497.8316	0.422442
0.2	1243.306	248.6613	8	23.62069	615.8025	0.495294
0.2	1285.169	257.0338	8	23.2683	775.3775	0.603327

Table 7: Experimental results of flat plate collector with vacuum enclosure



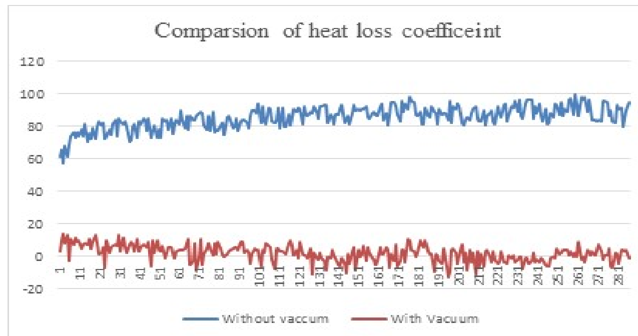
The above graph illustrates the thermal losses of the collector system with evacuated enclosure. After employing vacuum pressure in the system, no matter the vacuum concept worked effectively in enhancing the efficiency of the collector but at the same time it also caused to increase the thermal losses from the collector system. As we can see from the above figure, there is an increasing trend of thermal losses with respect to mean plate temperature, however the heat losses decreased when employing the vacuum environment in graph as compared non vacuum one

Comparison between Vacuum and Non Vacuum thermal efficiencies:



The above graph illustrates the thermal efficiency obtained against time graph for both evacuated and non-evacuated flat plate collector system. The graph represents clearly that the efficiency achieved in case of evacuated system is significantly high as compared to non-evacuated system. The thermal efficiency of evacuated system depicts the increasing trend from initial level itself and reaching to the peak value of 60% within a time period of 80 minutes while on the other hand the thermal efficiency in case of the non-evacuated system increased marginally at the initial stage and was further maintained stable till its last stage. The effect of employing the vacuum pressure within the system has drastically suppressed the two main convection and radiation losses as discussed in above literature review. However the vacuum pressure did not have much effect on reducing the overall heat losses but as it showed a considerable effect on enhancing the thermal efficiency. The thermal efficiency to about 40% increased when employing the flat plate collector with vacuum enclosure as compared to the normal collector system. As we determined that the maximum vacuum pressure of 50Kpa gives us the highest thermal efficiency value to about 60% for a mass flow rate of 2 liters per minute while decreasing the pressure will result in loss of efficiency which is undesirable.

Comparsion of heat loss coefficient in case of Evacuated and Non evacuated system:



The above graph depicts the varying heat loss coefficient in comparison to evacuated and non-evacuated system. Here it can be seen that the heat loss coefficient directly proportional to the thermal efficiency of the system. As the thermal efficiency increases it causes to decrease the heat loss coefficient. As we can see from the above graph in case of vacuum evacuated system shown by red line the heat loss coefficient was fluctuating between 0 to 15 W/m^2K but on the other hand in non-vacuum case the loss coefficient reached a peak value of 100 W/m^2K shown by blue line was fluctuating in the range of 60 to 100 W/m^2K which is considerably high that caused to achieve low thermal efficiency. Employing moderate vacuum pressure in solar flat collector played a dominant role in suppressing the overall heat loss coefficient and improving the thermal performance of the collector system.

V. CONCLUSION

In this research project, important consideration was taken into account for the development of vacuum evacuated solar flat plate collector. The experimental and analytical outcomes were calculated and reviewed as a result to examine the influence of the vacuum environment on the collector system. A foam material was used as a sealing material to maintain the vacuum pressure within it. Solar absorber plate was placed in the vacuum chamber to a pressure of 50KPa assuring that no leaks are present in the system. Fluid inlet, outlet and vacuum port was designed and developed in a proficient manner to ensure no vacuum leakage takes place within the system. The vacuum envelope acted as a catalyst in suppressing the heat losses from the collector and enhancing the thermal efficiency. Several graphs have been plotted regarding the thermal energy losses, thermal efficiency, varying mass flow rate, plate thickness etc. as result to analyse the effectiveness of the solar flat plate collector system. Overall the collector system has been analyzed by considering evacuated and non-evacuated type in order to view the error in the estimation of the temperature. The efficiency of the collector system of the proposed was established on the basis of result outcomes obtained from experimental work. The analysis depicts the better relationship between the experimental and analytical values for varying flow rate and working conditions.

VI. RECOMMENDATIONS

- Much of the thermal efficiency of the system can be increased by operating the collector system on high vacuum pressure instead of moderate vacuum.
- The thermal energy loss in the system can be reduced and useful gain in thermal energy can be obtained by employing the inert filling gases such as argon and Krypton etc. within the collector chamber.
- The overall thermal performance of the system can be enhanced significantly when subjected to outdoor condition where bright sun is available instead of using the manual halogen bulb arrangement methodology.
- Fin efficiency can be increased by reducing the plate spacing in between the tube conduits.
- Operating fluid such as water can be changed with other high conductivity fluid in order to obtain a high thermal efficiency of the collector system.
- Rollers can be employed at bottom of the system so that it becomes possible to move the system to any desired location where higher solar energy can be obtained.

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