THERMAL PERFORMANCE AND ANALYSIS OF A SOLAR WATER HEATING SYSTEM WITH HEAT PIPE EVACUATED TUBE COLLECTOR

Kiran K Murali[1], S Rajesh[2]

[1]*Kiran K Murali, Mechanical Engineering Department, Narsimha Reddy Engineering College, Secunderabad, Telengana 500100, India*
[2]*S Rajesh, Assistant Professor, Mechanical Engineering Department, Narsimha Reddy Engineering College, Secunderabad, Telengana 500100, India*

---***---

Abstract - *The research and studies about the Solar Water Heating System (SWH) shows that, using the evacuated tube collector with heat pipe technology has the best performance among all the other systems. There must be some improvements are needed to the evacuated tube system with heat pipe technology for better efficiency and effectiveness. I selected three materials namely aluminium, copper and aluminium alloy 6061 as the base material for the heat pipe. The thermal analysis and performance analysis (CFD analysis) is carried out for different mass flow rates to get the best optimized heat transfer rate and heat flux rates. Also the theoretical calculations using the heat transfer equations are also evaluated. At the end of the analysis and comparison I reached in a result that the copper is best as the manufacturing material for the heat pipe in evacuated tube collector of a solar water heating system due to its higher heat transfer and heat flux rates.*

***Key Words*: Solar Water Heating System, Evacuated tube collector, Aluminium, Copper, Aluminium alloy 6061, Thermal analysis, Performance analysis, Heat transfer, Heat flux rates**

1. INTRODUCTION

Solar water heating (SWH) is a technique in which the solar energy from the sun is used for water heating by the use of solar thermal collector. In market a wide range of configurations are available for different environmental conditions. They are widely used for domestic and industrial usage. The working fluid is heated by a sun facing collector and passes into a storage system. They use water only, or the combination of water and antifreeze working fluid. Light concentrating mirrors are used for direct heating the system. Because mirrors can concentrate the sunlight into smaller collectors in heavy duty installations.

1.1 Problem Definition

Solar water heating system installed with evacuated tube collector configuration is available for the last two decades. The main components inside the system are the absorber material and the heat pipe. By using a variety of materials as the base metal of the heat pipe the efficiency and effectiveness of the system can be improved. Due to the low temperature operation of the system, mainly it is used for domestic and small scale industrial purpose.

Here I am comparing aluminium, aluminium alloy and copper alloy as the base metal of the heat pipe and find the heat transfer rates and heat flux rate. From this comparison of these low cost metals I can find which is best for the heat pipe of the evacuated tube collector.

2. DESIGN AND ANALYSIS

2.1 Heat Pipe Technology

Heat pipe is a device that promotes heat transfer by the application law of thermal conductivity and phase transition .The heat pipe is divided into an evaporation part and condensation part. An anti freezing liquid is circulating inside the heat pipe. One end of the heat pipe is connected to a manifold that carries cold water from the overhead tank and supplies hot water from the solar water heater by heat exchange process. The solar radiation incident on the evacuated tube reaches the heat pipe through vacuum. It heats the liquid inside the tube and changes into vapour. Due to density difference the hot vapour reach the other end which is connected to the manifold. The heat from the pipe is transferred to the cold water in the manifold and converts into hot water. This hot water goes through the pipeline. The vapour due to condensation now turns into liquid and due to the gravity and capillary action it goes to the evaporation side and the cycle continues.

2.2 Boundary Conditions

Sl.No	Dimension (mm)	Mass flow rate (kg/s)
1	50	0.006
2	100	0.008
3	150	0.015
4	200	0.02

2.3 CFD Analysis of Solar Water Heater

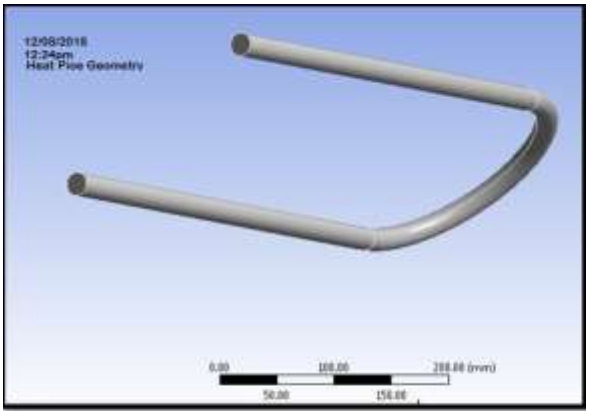


Fig-1: Geometry of heat pipe

Mass flow rate – 0.006kg/s

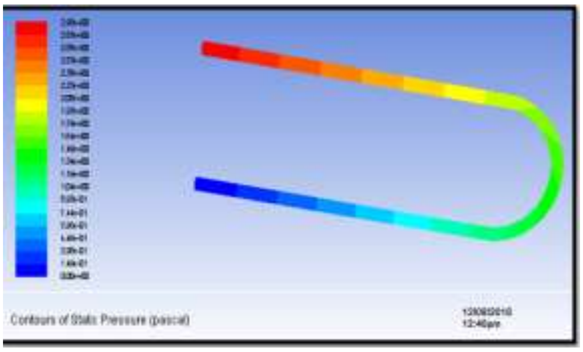


Fig-2: Contours of Pressure

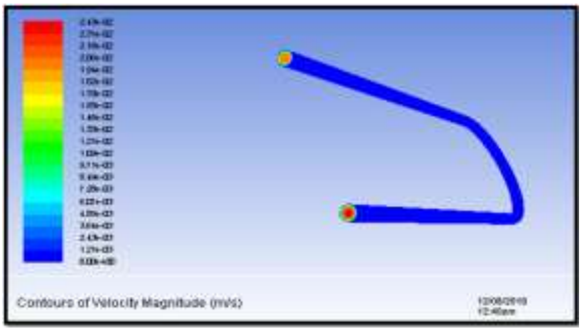


Fig-3: Contours of Velocity

MASS FLOW RATE

Mass Flow Rate	(kg/s)
inlet	0.0059999996
interior-____msbr	-2.503412
outlet	-0.0060006455
wall-____msbr	0
Net	-6.6459179e-06

HEAT TRANSFER RATE

Total Heat Transfer Rate	(w)
inlet	1878.1362
outlet	-1880.2151
wall-____msbr	0
Net	-2.0788574

Mass flow rate -0.008kg/s

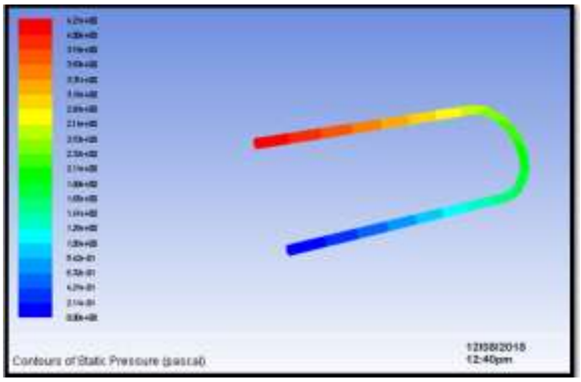


Fig-4: Contours of Pressure

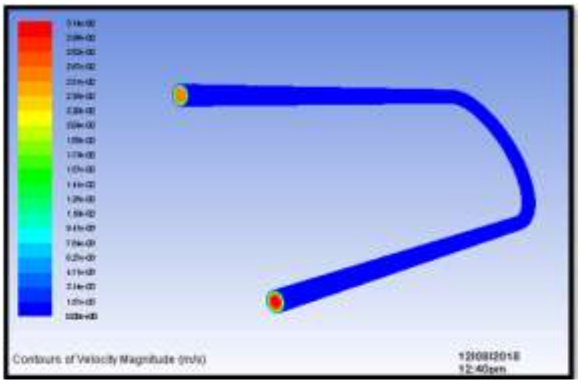


Fig-5: Contours of Velocity

MASS FLOW RATE

Mass Flow Rate	(kg/s)
inlet	0.0080000013
interior-____msbr	-3.3359661
outlet	-0.0079953074
wall-____msbr	0
Net	4.6938658e-06

HEAT TRANSFER RATE

Total Heat Transfer Rate	(w)
inlet	2504.1824
outlet	-2502.7114
wall-____nsbr	0
Net	1.4709473

Mass flow rate -0.015kg/s

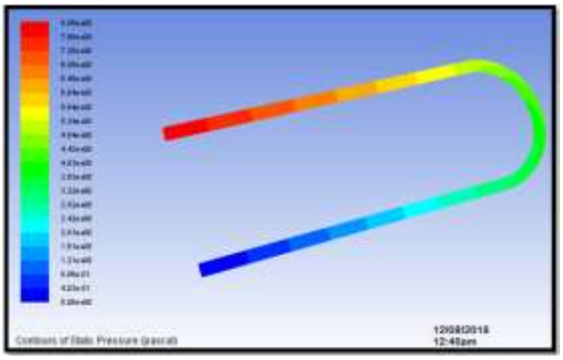


Fig-6: Contours of Pressure

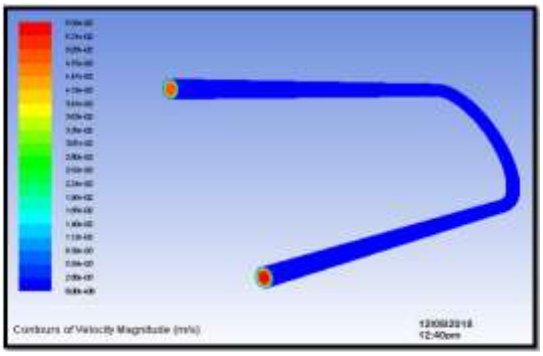


Fig-7: Contours of Velocity

MASS FLOW RATE

```
          Mass Flow Rate                 (kg/s)
-------------------------- --------------------
                    inlet            0.014999997
         interior-____msbr            -6.2576375
                   outlet           -0.014996917
              wall-____msbr                     0
              ---------------- --------------------
                      Net          3.0798838e-06
```

HEAT TRANSFER RATE

```
     Total Heat Transfer Rate                   (w)
-------------------------------- --------------------
                          inlet            4695.3403
                         outlet           -4694.3867
                   wall-____msbr                    0
                ---------------- --------------------
                            Net           0.95361328
```

Mass flow rate -0.02kg/s

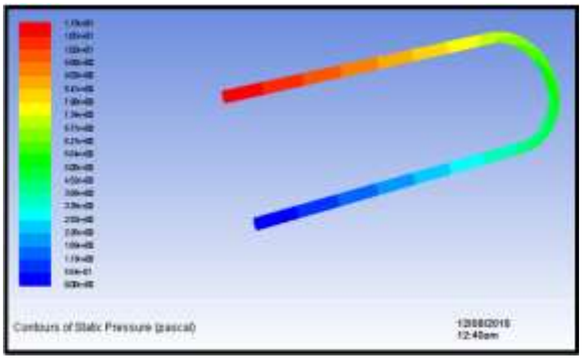


Fig-8: Contours of Pressure

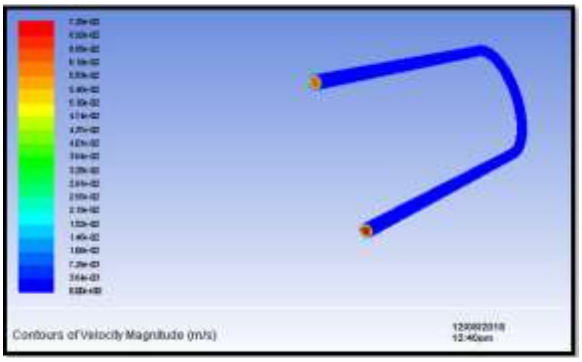


Fig-9: Contours of Velocity

MASS FLOW RATE

```
          Mass Flow Rate                 (kg/s)
-------------------------- --------------------
                    inlet            0.020000005
         interior-____msbr            -8.3427544
                   outlet           -0.020016998
              wall-____msbr                     0
              ---------------- --------------------
                      Net          -1.6992912e-05
```

HEAT TRANSFER RATE

```
     Total Heat Transfer Rate                   (w)
-------------------------------- --------------------
                          inlet            6260.4536
                         outlet           -6265.7798
                   wall-____msbr                    0
                ---------------- --------------------
                            Net           -5.3261719
```

2.4 Thermal Analysis of Solar Water Heater

Material	Thermal Conductivity	Specific Heat j/kg^{0}C	Density (kg/mm^3)
Copper	385w/mk	0.385	0.0000077
Aluminum	385w/mk	0.9000	0.0000026989
Aluminum alloy 6061	385w/mk	0.8961	0.00000270

Thermal analysis of copper material

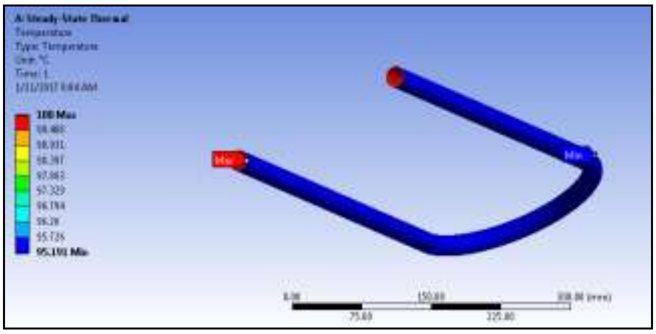


Fig-10: Temperature

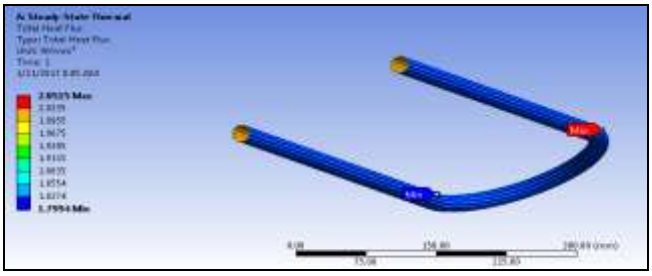


Fig-11: Heat flux

Thermal analysis of aluminium material

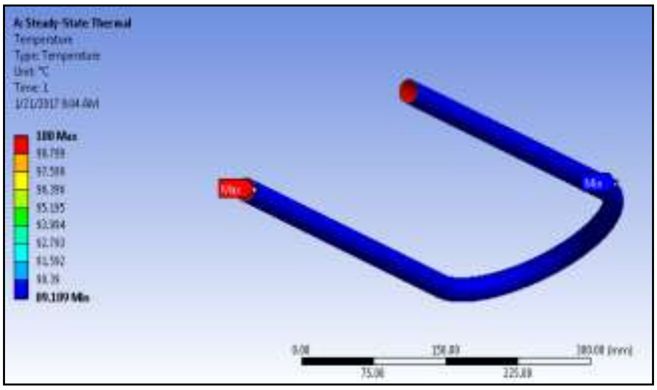


Fig-12: Temperature

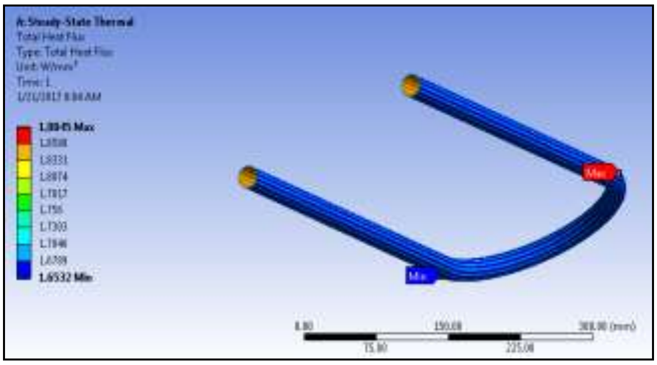


Fig-13: Heat flux

Thermal analysis of aluminum alloy 6061 material

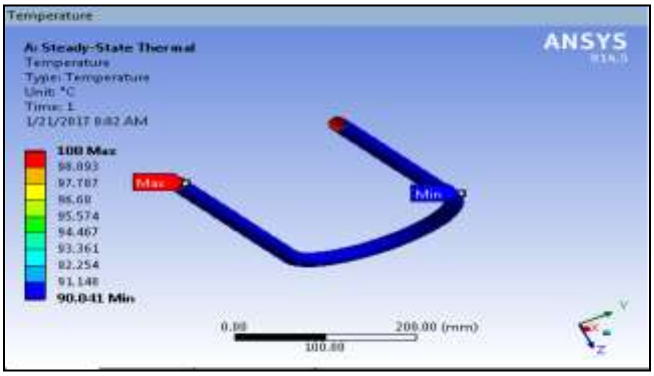


Fig-14: Temperature

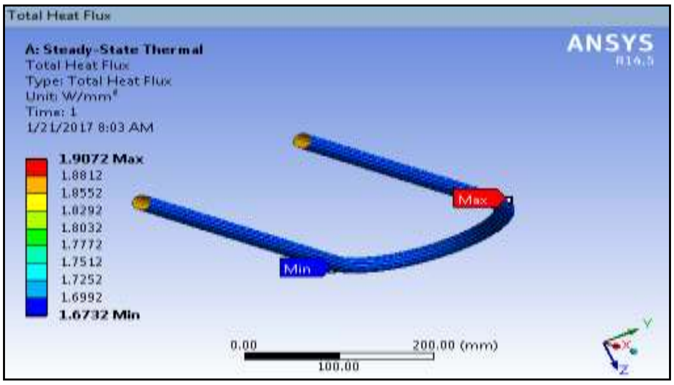


Fig-15: Heat flux

3. RESULTS AND GRAPHS

3.1 Results

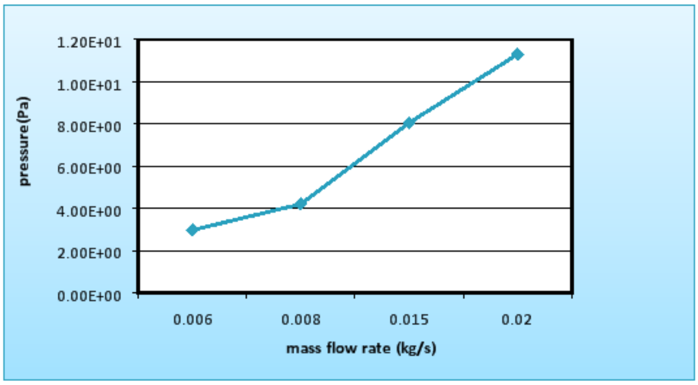
Flow(Kg /s)	Pressure (Pa)	Velocity (m/s)	Mass flow rate (kg/s)	Heat transfer rate (W)
0.006	2.98e+00	2.43e-02	6.6459e-06	2.0788574
0.008	4.21e+00	3.14e-02	4.6938e-06	1.4709473
0.015	8.06e+00	5.59e-02	3.07988e-06	0.95361328
0.02	1.13e+01	7.29e-02	1.69929e-05	5.3261719

3.2 Thermal Analysis

Material	Temperature (^0C)	Heat flux

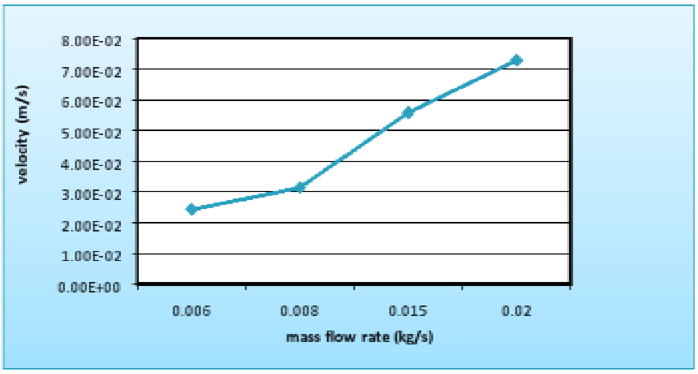
	Max	Min	W/m²
Aluminum	100	89.189	1.8845
Aluminum alloy 6061	100	90.041	1.9072
Copper	100	95.191	2.0515

3.3 Graphs



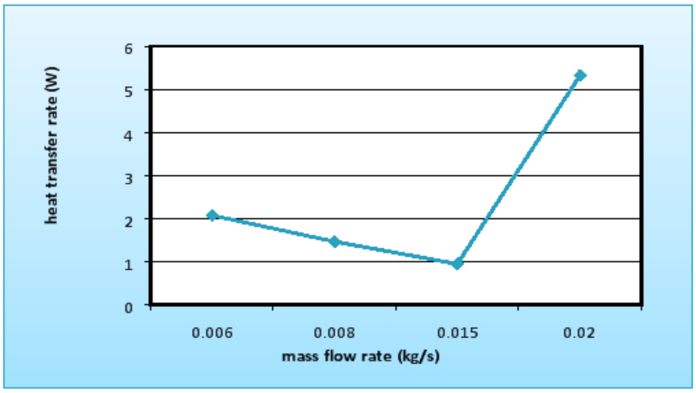
Pressure increased linearly with increase in the mass flow rate

Fig-16: **Pressure Plot**



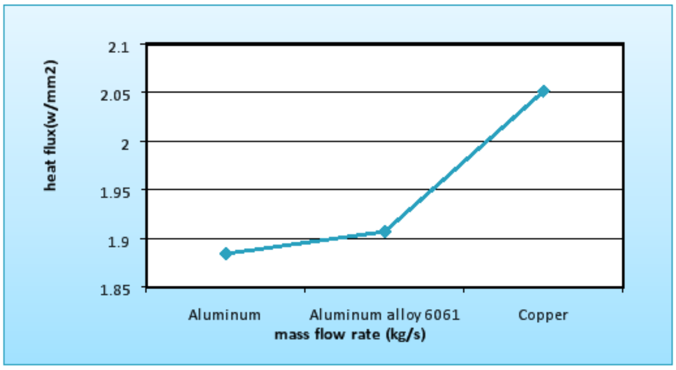
As the mass flow rate increases the velocity of the flow get increased linearly

Fig-17: **Velocity Plot**



As the mass flow rate increasing the heat transfer firstly decreases then a steep increase in the heat transfer between 0.015 and 0.02

Fig-18: **Heat Transfer Rate Plot**



The heat flux bear a linear relationship between mass flow rates. The heat flux rate is maximum for copper alloy and minimum for aliminium

Fig-19: **Heat Flux Plot**

4. CONCLUSIONS

The steam flow in solar water heater tubes is modelled using PRO-E design software in this work. The project will focus on thermal and CFD analysis with different flow rates (0.006, 0.008, 0.015& 0.02m/s). Thermal analysis done for the solar water heater by aluminum, aluminium alloy 6061& copper alloy at water heat transfer coefficient values.

By observing the CFD analysis the pressure drop, velocity, mass flow rate & heat transfer rate increases by increasing the inlet flow rates.

By observing the thermal analysis, Heat flux value is more for copper alloy material than aluminum and aluminum alloy 6061. About 9% increase of heat flux rate for copper alloy as compared with aluminum and 7% increase as compared with aluminum alloy 6061.

So I can conclude that copper alloy material is better for heat pipe in an evacuated tube collector solar water heater.

5. REFERENCES

[1] Abdul Waheed Badar, (2012) – SINGLE AND TWO-PHASE FLOW MODELLING AND ANALYSIS OF A COAXIAL VACUUM TUBE SOLAR COLLECTOR”

[2] Aminreza Noghrehabadi (2015) - “AN EXPRIMENTAL STUDY OF THE THERMAL PERFORMANCE OF THE SQUARE AND RHOMBIC SOLAR COLLECTORS”

[3] Bobin K. Mathew (2016) “ PERFORMANCE ANALYSIS OF SOLAR THERMAL EVACUATED TUBE COLLECTOR USING DIFFERENT NANOFLUIDS”

[4] I.George (2017) - "OPTIMIZATION OF THERMAL PERFORMANCE ON EVACUATED TUBE SOLAR COLLECTOR Water HEATING SYSTEM "

[5] Lacour Ayompe (2013) - "THERMAL PERFORMANCE ANALYSIS OF A SOLAR WATER HEATING SYSTEM WITH HEAT PIPE EVACUATED TUBE COLLECTOR USING DATA FROM A FIELD TRIAL.

[6] Morrison G (2004) - "WATER-IN-GLASS EVACUATED TUBE SOLAR WATER HEATERS"

[7] Raghurajsinh .B (2016) – PERFORMANC OF AN EVACUATED TUBE COLLECTOR WITH HEAT PIPE TECHNOLOGY"

[8] ZambolinE (2010) - "EXPERIMENTAL ANALYSIS OF THERMAL PERFORMANCE OF FLAT PLATE AND EVACUATED TUBE SOLAR COLLECTORS IN STATIONARY STANDARD AND DAILY CONDITIONS"

[9] Zambolin E (2012) - "AN IMPROVED PROCEDURE FOR THE EXPERIMENTAL CHARACTERIZATION OF OPTICAL EFFICIENCY IN EVACUATED TUBE SOLAR COLLECTORS"

[10] Zubriski S E (2012) - "MEASUREMENT OF THE EFFICIENCY OF EVACUATED TUBE SOLAR COLLECTORS UNDER VARIOUS OPERATING CONDITIONS"