The performance measurement of the parabolic trough solar collector

Jozef Matusov, Peter Durcansky, Richard Lenhard

Abstract - The performance of the parabolic collector depends on several factors such as the size and shape of the parabolic trough collector, shape and area of the focal heat exchanger and optical properties. Another very important parameter that depends on the position and location of the solar collector is a value of the intensity solar irradiation. The performance measurement of the collector was carried out in the northern part of Slovakia, in the city Zilina. The captured solar energy in the form of sunlight by solar trough collector was concentrated to focal heat exchanger. Subsequently this energy was changing into a thermal energy. The thermal energy was led away from the focal heat exchanger by means of a heat-transfer medium. This paper deals with performance measurement of parameters of the parabolic trough collector with absorption area 10.25 m^2 and real area of focal heat exchanger 1.66 m^2.

Keywords – flow, intensity of solar radiation, parabolic trough collector, sensors

I. Introduction

Every type of solar collector captures sunlight and converts it to a thermal energy [1]. In general the collectors are divided into two main types. There are flat and concentrating collectors. For reaching higher temperatures of heat-transfer media are used the concentrating parabolic collectors [2].

In our case we have dealt with designing of the parabolic trough solar collector (Fig. 1), which would be able to heat the heat-transfer medium - air on approximately temperature 300 °C. This temperature and amount of energy would be sufficient for starting a hot-air engine [3]. Therefore, the overall dimensions of the collector based on the parameters of the hot-air engine. In the theoretical way it was expected, that thermal performance could be achieved 3-5 kW. After calculating the intensity of solar irradiation for city Zilina, was determined the surface area of collector 10.25 m2, where width is 1,744 m and length is 5.88 m. The reflective surface of collector is covered by special solar film from company 3M and its name is 3M Solar Film 1100 with 94% reflectivity [4].

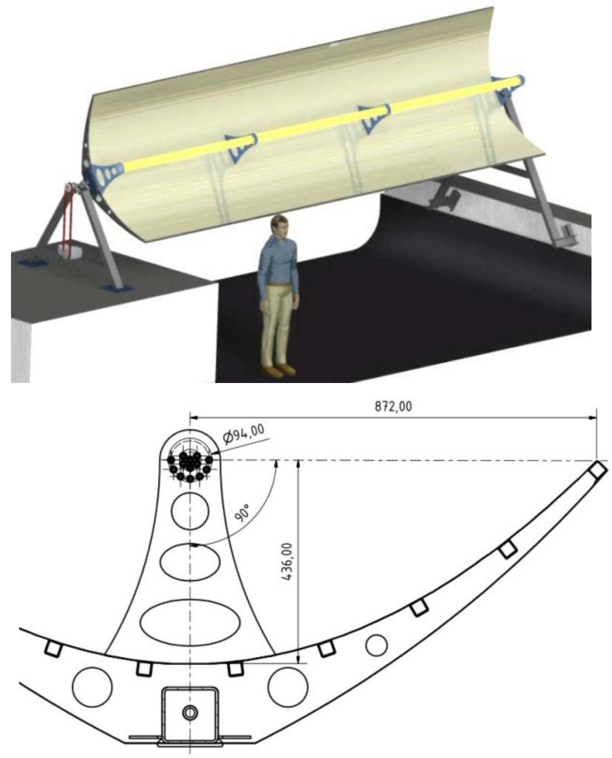

Fig. 1 The 3D model of the parabolic trough solar collector and main collector dimensions.

Another designed part of collector was the heat exchanger which was situated in the focus of parabolic trough solar collector. The estimated pressure value of the heat-transfer medium was 1 MPa in the whole system. This heat exchanger consists of thirteen pipes, and every pipe has outer diameter 12 mm, wall thickness 2 mm and length 5.869 m [11].

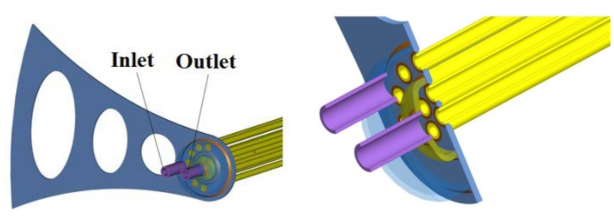

Fig. 2 Inlet and outlet working fluid - air from the heat exchanger.

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Numerical part of this work had been solved by Jozef Matusov in the Institute for Energy Systems and Thermodynamics, Vienna University of Technology, three-month internship supported by program Action Austria – Slovakia.

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The exchanger has two parts (Fig. 2). The first (9-12) - the entrance part consists of six pipes and the second (1-7) - the output part consists of the seven pipes [5]. The material of pipe is EN 1.7715 (14MoV6-3). The pipes of heat exchanger were painted with a special selective coating with an absorption coefficient of 0.9 [6].

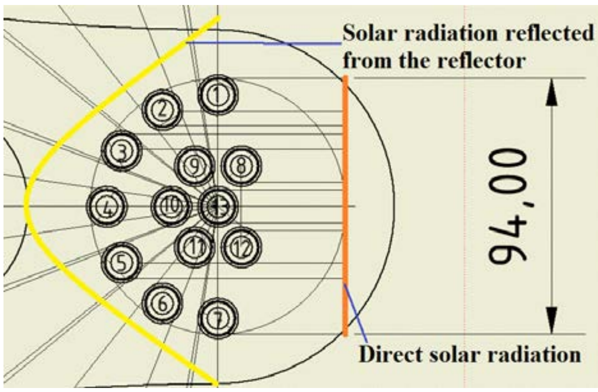

Fig. 3 Ideal impact of solar radiation to pipes of the focal heat exchanger.

The amount of incident energy for each pipe was found graphically in program Autodesk Inventor from the 3D model of the heat exchanger, which is identical to real one. In the figure (Fig. 3) is shown the solar radiation incidence on the pipes of heat exchanger and their mutual shielding. From the analysis were obtained the size of the light surfaces for every tube [7].

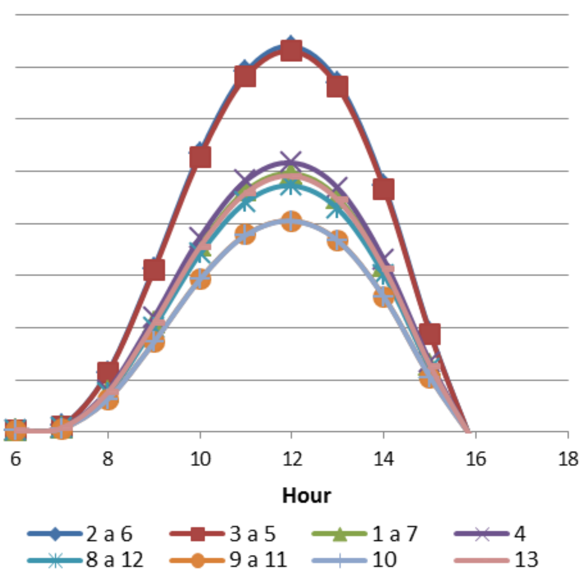

Fig. 4 Range of heat flow for every pipe of heat exchanger dependent on optical efficiency and date in year.

The graph (Fig.4) was constructed based on graphical analysis, optical efficiency calculation and amount of solar radiation during day where is see, that the greatest amount of heat flow passes through the tubes labeled 2 and 6. If the solar energy was absorbed to each pipe in same amount it would be ideal case.

II. Connecting Diagrams of Sensors and Components of the Measuring System

For determining of performance parameters of the parabolic trough collector was designed connection diagram of the main components and sensors. The type and range of sensors was chosen on the basis of the input and output values from the numerical calculation of exchanger collector. The amount of volumetric flow to heat exchanger was set to the condition that the velocity of the air in the pipes exchanger did not exceed 15 m/s. This condition was taken over from the theory of calculation exchangers to heat the working fluid air [8]. The number of sensors for measuring instantaneous values of temperature, pressure, flow rate and intensity of solar radiation is the same as is shown in the picture (Fig. 5).

For the performance measurement of focal heat exchanger was necessary to set up value of air flow rate [9]. The air passing through the focal exchanger was heated from the inlet temperature to the outlet temperature. Slide valve was installed for the setting pressure on the end of the output pipe from the exchanger. The compressed air was delivered to compressor from surrounding atmosphere and its capacity was 25 m^3 per hour with outlet pressure 900 kPa. From the compressor was delivering the air to pressure tank with capacity 1000 liters. The measurement was run on the basis of specified pressure and mass flow.

In the assembly of experimental devices were placed the following sensors of:

- pressure – Ahlborn FD 8214 12R with measuring range 0÷10 bar,
- temperature – air in the storage tank ZA9030-FS2 (Pt 100, from - 200 to 400°C), air in atmosphere FTA683-2 (Ni-Cr-Ni, from - 100 to 200°C), air in the heat exchanger ZA9030-FS (NiCr-Ni, till 870 °C),
- flow – rotary piston gas meter PREGAMAS G65 DN 50 with high-frequency pulser A1K, with number of impulses 14025 per $1m^3$,
- meteorological station – wind direction FV614, wind velocity FAV6152, intensity of solar radiation for global sunlight FLA613GS.

All sensors were connected to a measurement logger and from there subsequently to a computer. Measured values as a temperature, pressure, intensity of solar radiation and flow rate were saved to memory at 10 second intervals. These values were automatically written to a spreadsheet program Microsoft Excel.

III. Course of the Performance Measurements of the Parabolic Trough Solar Collector

The experimental measurements were possible done only during direct sunlight, because this type of collector isn't able to convert different type of solar sunlight to heat energy in the focal heat exchanger. If the amount of clouds are increasing, collector performance is decreasing rapidly.

During the measurement of performance trough solar collector, the permanent volume flow of the air was 3.75 dm^3/s. The excess pressure 0.5 bar was set up with a slide valve in the system. Other values were measured on the basis of the current state, which depended on the intensity of solar radiation, ambient temperature and an incidence angle of the solar radiation. For achieve the best possible performance, was necessary constantly turning an absorption area of trough solar collector directly to the Sun (Fig. 6).

Fig. 6. Turning of the trough solar collector during the measurement

The measurements of the parabolic trough collector usually lasted 140 -150 min.

In this paper are shown results of the measurement which started in time 9:05 with intensity of solar radiation 610 W/m^2. In this time was calculated optical efficiency 0.7 and heat flux 4.37 kW. The maximum value of the air temperature was 116.5 °C reached in 120th minute of measurement, when the intensity of solar radiation was 867 W/m^2.

During the measurement, we found that the contractor of collector fixed the ends of focal exchanger tubes and thus limited the effect of thermal expansion. This caused the change in the geometry pipes of the focal exchanger (Fig. 7) [12].

Fig. 7 Change the shape geometry of pipes in the focal heat exchanger.

IV. Measurement Results

Heat performance of the focal heat exchanger was calculated according to calorimetric equation (1) from the inlet and outlet air temperature from the heat exchanger, the mass flow rate and specific heat capacity of air for a medium value of temperatures [10].

$$\dot{Q} = \dot{m}.c_p.(t_{outlet} - t_{inlet})\,[\mathrm{W}] \quad (1)$$

The focal exchanger is divided on two parts, therefore were recorded three types of temperatures which are shown in the graph (Fig. 8):

- inlet temperature to the heat exchanger (Inlet)
- temperature of the tube plate (Solar 1)
- outlet temperature from the heat exchanger (Outlet).

From these three temperatures were calculated performance of the first part and the second part of the exchanger and also the total performance of the focal heat exchanger.

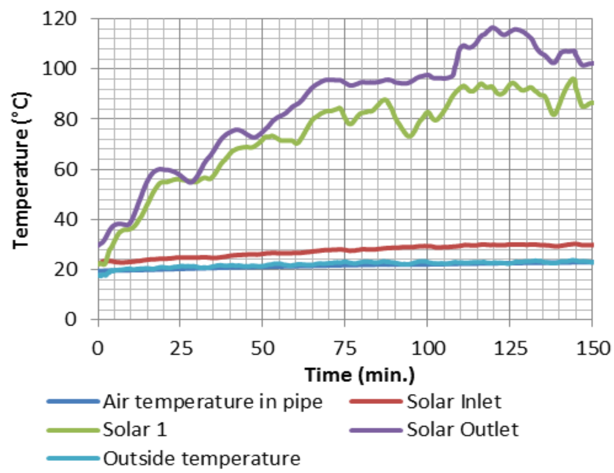

Fig. 8 Course of temperatures during performance measurement of the focal exchange

Mass flow rate of air was constant in the heat exchanger and its value was 6.7 g/s. In the graph (Fig. 10) is shown the dependence of the total performance on the intensity of incident solar radiation on 1 m^2. Significant effects on the performance of heating air in heat exchanger have: the ambient temperature, wind speed and direction, accuracy of rotation collector to the Sun. In the pictures (Fig. 9, Fig. 10) is possible see influence wind on overall performance during increasing the intensity of solar irradiation.

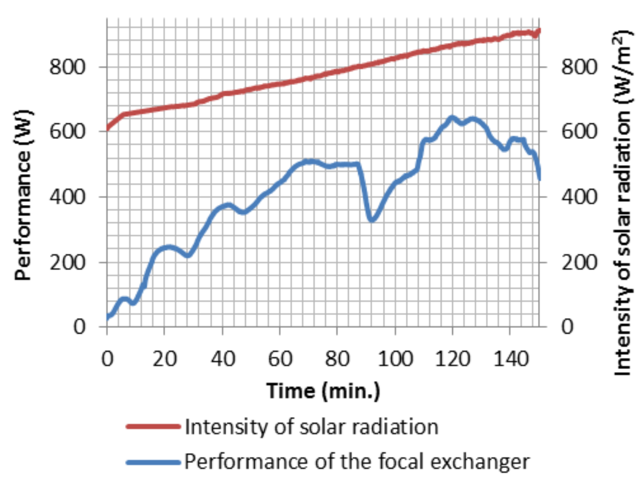

Fig. 10 Dependence of total performance of the focal heat exchanger on the intensity of solar radiation.

Numerical model was created according to theory Heat Transfer Analysis and Modeling of a Parabolic Trough Solar Receiver Implemented in Engineering Equation Solver [1]. Through calculation were obtained information about the energy gain for heating the heat transfer medium - air, depending on the amount of energy delivered by the energy source - the Sun. Considered parameters for calculation were: geometry exchanger and collector, optical characteristics, properties of heat transfer medium depending on pressure and temperature, inlet temperature, flow rate of the working fluid, the intensity of solar radiation, wind speed and ambient air temperature. From the calculation were obtained following values: the efficiency of the collector, the outlet temperature of the heat transfer medium, the quantities of heat energy, thermal, optical and pressure loss of the exchange. The equations include correlations, which is predicting the circumstances of in energy balance according to the type of the collector and the heat transfer medium, optical properties, and environmental influences.

V. Conclusion

From the measurements it was found, that the greatest impact on the performance of the focal exchanger had increase amount of clouds and the speed of wind which flows along the axis of focal exchanger. Another impact on the performances values was caused by changed shape of the pipes in the focal exchanger.

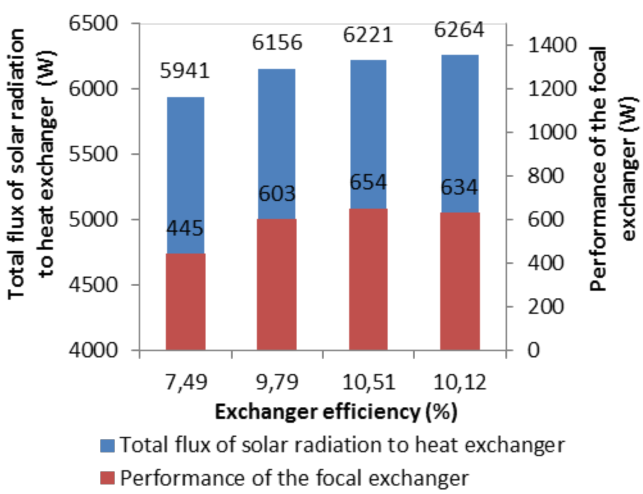

Fig. 11 Selected efficiency values

By calculation, but also by measurement were confirmed that the greatest loss of heat exchanger is caused by a free and forced convection to the surrounding area. The reducing of these losses would contribute to the increasing of overall performance. Therefore another research is dealing with the placing the focal exchanger into a glass-envelope with a vacuum process. This solution will increase the efficiency of heating the working medium.

During the measurements was achieved the highest efficiency 10.12% by heat performance 654.09 W (Fig. 11) and total flux value of solar radiation 6221 W.

Comparison of the measured values with mathematical model was done in program Excel, with the theoretical equations [1].

In this case is shown comparison, where was achieved the highest performance in the focal exchanger, under the following conditions:

- inlet air temperature at the exchanger 29.9 °C,
- air temperature at the tube plate with vaulted bottom 92.6 °C,
- outlet air temperature from the exchanger 116.5 °C,
- mass flow rate 6.7 g/s.
- absolute pressure 1.5 bar.
- heat flux of solar radiation incident on the exchanger 6220.7 W,
- wind speed 0.3 m/s and ambient air temperature 20.4 °C.

Required power obtained by calculating for heating of the air in the first part of the exchanger was 421.4 W, in the second part 162.3 W and total power required to heat the air was 583.7 W. From the entered values were calculated the losses which are shown in Table I.

Type of losses	1st part of exchanger	2nd part of exchanger	Total losses
Heat loss by free convection	1000.5 W	1572.5 W	2573 W
Heat loss by forced convection at a wind speed of 0.3 m/s	1772.8 W	1948.2 W	3721 W
Heat loss by radiation into the environment	805.1 W	978.8 W	1783.9 W

Table I. Heat loss calculations the heat exchanger.

The total required performance for heating the air from temperature 29.9 °C to 116.5 °C considering losses by wind, with velocity 0.3 m/s was 6088.6 W. In the case of windlessness the necessary performance was 4940.7 W. Wind effect acting on the pipes of exchanger caused the loss 1147.9 W.

The difference between the calculated and the measured value of required thermal performance is 132.1 W, what constitutes 2% deviation.

Acknowledgment

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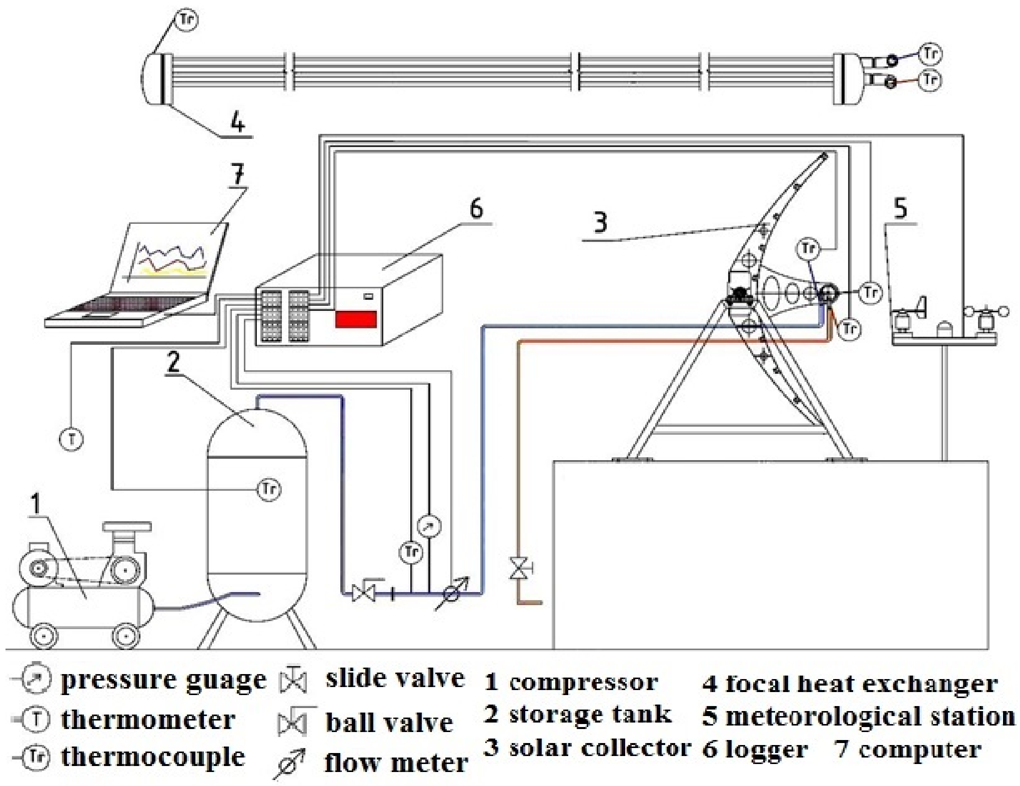

Fig. 5 Connection diagram of the components and sensors of experimental device for measuring performance parameters of heat exchanger in the focus of parabolic trough collector.