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Development and experimental study of the maximum temperature potential of a solar thermal module for driving of an absorption air-conditioning machine

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Abstract. *A solar thermal module intended for thermal driving of an absorption refrigeration machine for air conditioning of animal raising buildings was constructed and experimentally tested. The maximum temperature level of the heat agent in the module under the conditions of a clear and warm summer day of average solar radiation 950-970 W/m*^{2} *was determined. The effect of the mounting angle of the solar-thermal module on the maximum temperature levels of the heat agent circulating inside it was studied. Regression relationships between the maximum temperature of the heat agent in the thermal module and the theoretical heat coefficient of a conceptual absorption refrigeration machine, heat-driven by a solar thermal module, were determined*

Keywords: solar module, heat pipe, absorption refrigeration machine

Introduction

The use of solar radiation for production of heat energy is a technological solution known since ancient times (Lnigova, 1995). Design improvements in terms of optical properties and heat-absorbing characteristics of solar modules have turned them into a real alternative for "environmentally clean" heating of residential, public and industrial facilities (Dinev et al., 2006; Schneidler, 2006). Contemporary development of solar-collector systems has been moving from the principle of direct-flow thermal conduction to evaporation-condensation used in the development of vacuum tube collectors of the so-called "heat pipe" system (Shterev, 2007). This principal approach allows production of heat energy with a much higher temperature potential (above 80 C) in comparison with mainstream collectors of the so-called "flat plate" type (Dechev, 2009). The production of high-temperature heat from the sun is a real argument for rethinking of technological approaches in the air conditioning of public and industrial premises (Peychev et al., 2010).

The use of heat to drive refrigerating machines of the absorption type in the field of industrial air-conditioning is a "technological formula" which has been explored for some decades now (Christian, 1977). Among the advantages of these technical and technological solutions (as compared with compressor cooling systems) are absence of mechanically driven working components (except for a centrifugal water pump), longer operational life, no noise pollution and energy independence from electricity distribution companies (Todorov, 1977). Of utmost importance is the fact that absorption cooling engineering works with binary mixtures (excluding chlorine and fluorine substances) which makes it environmentally friendly (Kececiler, 2000).

The use of water solution of lithium bromide (H2O + LiBr) as a cooling binary mixture allows lowering the temperature levels of performance in the range of 60-80C (Guozhen, 2006). This temperature range provides a real opportunity to ensure adequate power from heat energy captured by solar thermal (collectors) modules to drive absorption cooling systems (Izquierdo; Kaynakli, 2007). Moreover, the U.S. government initiated the Solar Thermal Cooling program (development of solar air conditioner) and adopted the Energy Independence and Security Act governing the implementation of the program in the 2008-2012 period (http:en.Wikipedia.org/wiki/, 2007).

This brief overview clearly leads to a conclusion that this is a matter of current importance and there is a real need for technical and technological developments in the field of absorption air conditioning of public and industrial facilities through the use of low-potential thermal energy generated by thermal modules from solar radiation.

The purpose of this project was to conduct an experimental study of the maximum temperature level of the heat agent as achieved in an operating solar thermal module. The analysis of the data obtained was focused on the possibility to have a thermal powered absorption air conditioning machine (by a solar-thermal module) for animal raising applications.

Material and methods

The study was based on an effectively running solar thermal module, designed and constructed by the authors of this publication. Figure 1 gives a general view, while Figure 2 – a schematic diagram and the main functional members of the module. The photo-active section of the module consists of 5 thermal vacuum tubes (Heat Pipes) 1, converting solar radiation into thermal energy. They are connected in parallel with the manifold 2 where indirect heat exchange between the working fluid of the heat pipes and heat agent of the solar module takes place. A tubular circulation frame 3 made in metal galvanized pipes of diameter 1" is connected to both ends of manifold 2. The inside of frame 3 is filled with the heat agent of the module and functions as a heat accumulator. The circulation of the heat agent in manifold 2 and frame 3 is forced and is done by circulation pump 4. The pump works in automatic on-off mode controlled by differential thermostat 5. Depending on the preset hysteresis and current temperature readings of sensors a_1 and a_2 (fitted at both ends of manifold 2), the circulation pump 4 will be in working mode or turned off. Changes in the volume of the heat agent

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in the module are covered by expansion tank 6. The tank is open to the atmosphere, with provisions for additional sealing off. Upon closing of tank 6 pressure in the system is monitored by pressure gauge 7. Hydraulic protection 8 adjusted at 0.15 MPa overpressure is fitted to ensure complete safety for the solar module (against high pressure within a closed expansion tank).

Heat exchanger 9 with a copper pipe coil of length 2500 mm and diameter 22 mm is mounted on the tubular frame 3 of the module opposite the manifold 2. Within the so constructed solar thermal module the heat exchanger 9 is a conceptual analogue of the generator stage of an absorption refrigeration machine. The heat generated in the module and transferred by the coil will provide the energy needed for the running of a direct and a reverse process of a refrigeration (or air conditioning) machine of the absorption type. Swivel joints 10 and lever assembly 11 make non-discreet change of the mounting angle between the plane of heat pipes 1 and plane of horizon possible. The solar thermal module is mounted on wheel carriage 12. This allows easy and rapid orientation of the module towards the sun.

Within the time of the experiment the temperature change and maximum temperature levels of the heat agent in the solar thermal module were measured. Data was taken visually from the display of differential thermostat 5 in accordance with the readings of sensors a_1 and a_2. The measurement readout was timed at each change in temperature of the heat agent by 5° C, the "time axis" of the experiment was started at "zero" minutes. As maximum temperature potential of the solar thermal module was assumed the temperature level (temperature of heat agent) which remained unchanged for 30 minutes after the last readout.

The intensity of solar radiation at which experimental observations were made was determined by a pyranometer (Figure 3), consisting of a light sensitive device (photovoltaic panel) and a millivoltmeter as a measuring instrument. Data from measurements were processed using the expression:

$$I_0 = k.U,\ W/m^2 \qquad (1)$$

I_0 – solar radiation intensity against plane of horizon, W/m^2;

U – voltage measured (by voltmeter) at the output of pyranometer, mV;

κ – calculated coefficient

κ = 77.76 W/mV.m^2

The maximum potential temperature of the module was studied for three alternative "mounting" angles α = 20˚, 30˚, and 40˚. Experimental measurements were taken in the time interval from 10:00 to 16:00 hours within the period from 05.08.2010 to 28.08.2010. During the study the longitudinal axis of the solar

Figure 1. General view of a solar thermal module for thermal driving of an absorption refrigeration machine.

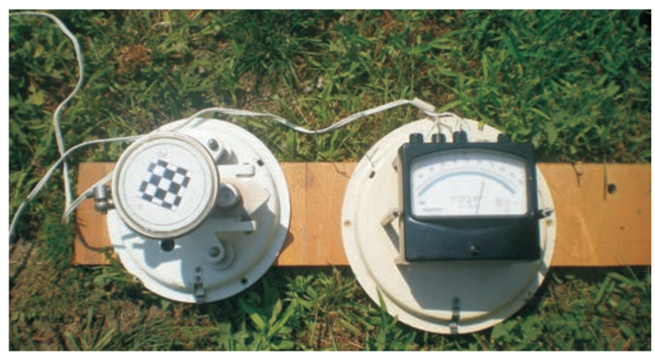
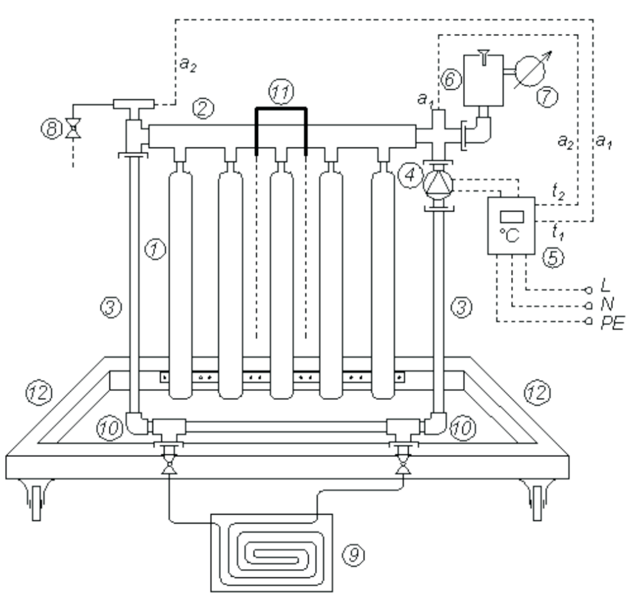


Figure 3. General view of a pyranometer assembly unit for measurement of solar radiation intensity.



1–photoactive section of thermal vacuum tubes;
2–manifold;
3–tubular circulation frame;
4–circulation pump;
5– differential thermostat on single phase electric power supply;
a_1–"low temperature" sensor;
a_2–"high temperature" sensor;
6–"open" expansion vessel with provisions for atmospheric sealing off;
7–pressure gauge;
8–hydraulic protection;
9–external heat exchanger of the generator of an absorption refrigeration machine;
10–swivel joints;
11–lever assembly for change of mounting angle;
12–wheel carriage.

Figure 2. Schematic diagram of a solar thermal module for driving of an absorption refrigeration machine

thermal module was oriented "north-south". No adjustments in the orientation of the module were made to follow the azimuth change of solstice. Throughout the experimental period weather was predominantly clear and sunny, at ambient temperatures from 23.4˚ to 33.4˚ C.

Obtained data for change of heat agent temperature in manifold 2 of the solar thermal module were analyzed in two aspects:

- graphical interpretation of heat agent temperature changes within the operating time of the solar thermal module;
- effect of mounting angle α on maximum temperature of the heat agent in manifold 2 of the solar-thermal module. In general, the effect studied was described using the following function:

$t_{max} = f(\alpha)$, ˚C (2)

where:

t_{max} – maximum value of heat agent temperature in the module, ˚C;

α – mounting angle between the plane of heat pipes and plane of horizon, 20˚, 30˚, and 40˚.

Based on the data obtained and the method of least squares, an equation for linear regression of maximum temperature in the solar thermal module on its mounting angle to the horizontal plane was derived:

$t_{max} = a + b\alpha$ (3)

Measured temperature maximums were considered to determine the possibility to use the heat of solar-thermal module to power an absorption refrigeration (air conditioning) machine. For this purpose, the so-called theoretical thermal coefficient ζ, expressing the ratio of the cold production obtained and heat consumed for the "direct" and "reverse" process of the absorption refrigeration (air conditioning) machine was used as an indicator of the expected cooling effect:

$$\varsigma = \frac{T_h \quad T_k}{T_h} \cdot \frac{T_k}{T_k \quad T_o} \qquad (4)$$

where:

ζ – theoretical value of the heat coefficient;

T_h – absolute temperature of heat agent of the solar thermal module, ˚K;

$T_к$ – absolute temperature of condensation (ambient) ˚K;

T_o – absolute temperature of cooled environment ˚K.

For the purposes of calculation, 10˚ C was assumed as a (conditional) temperature of cooled environment (temperature of evaporation of refrigerant). Using the method of least squares, an equation for linear regression of the theoretical value of the heat coefficient ζ on temperature of the heat agent in the solar thermal module was derived:

$\zeta = a + b.\ t_{max}$ (5)

Results and discussion

Graphical profiles of the temperature changes measured for the three alternative mounting angles α are presented in Figures 4, 5, and 6. In this experiment, for mounting angle α = 20˚ the maximum temperature of the heat agent determined was 115˚ C. Registration of that maximum was obtained around the 90th minute from the start of the experiment. In the next 30 minutes of measurements the temperature of the heat agent remained at the same level (115˚ C) which gave us reasons to assume that for a mounting angle of 20˚ and under the conditions of solar radiation average intensity Io = 964.2 W/m2 and ambient temperature about 32˚ C, the maximum temperature potential of the solar module is 115˚ C.

Nearly throughout the range of measurements the rate of temperature change was uniform, with some deviations at the 10th and 40th minute from the start of the experiment. On the basis of the maximum temperature obtained a theoretical heat coefficient ζ of value 2.97 was determined. This result gives reason to assume that the development of an absorption refrigeration (air conditioning) module, heat powered at a level of 115˚ C would realize a relatively high efficiency of operation. The dynamics of temperature changes of the heat agent in the solar thermal module at mounting angles of 30˚ and 40˚ was similar to that described at an angle of 20˚. The main

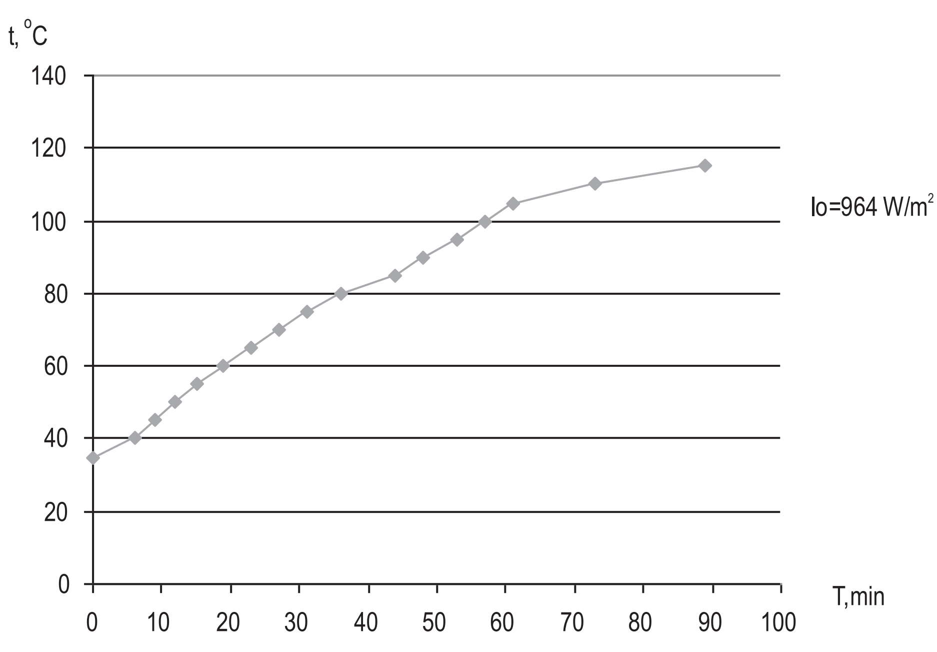


Figure 4. Graph of temperature changes of the heat agent in the thermal collector module at mounting angle α=20° (Io – solar radiation intensity, W/m²).

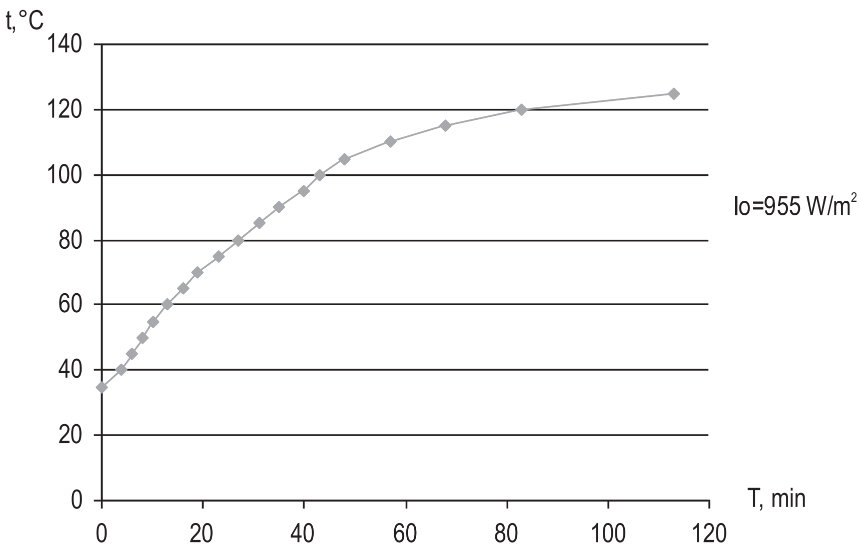


Figure 5. Graph of temperature changes of the heat agent in the thermal collector module at mounting angle α=30° (Io– solar radiation intensity, W/m^2).

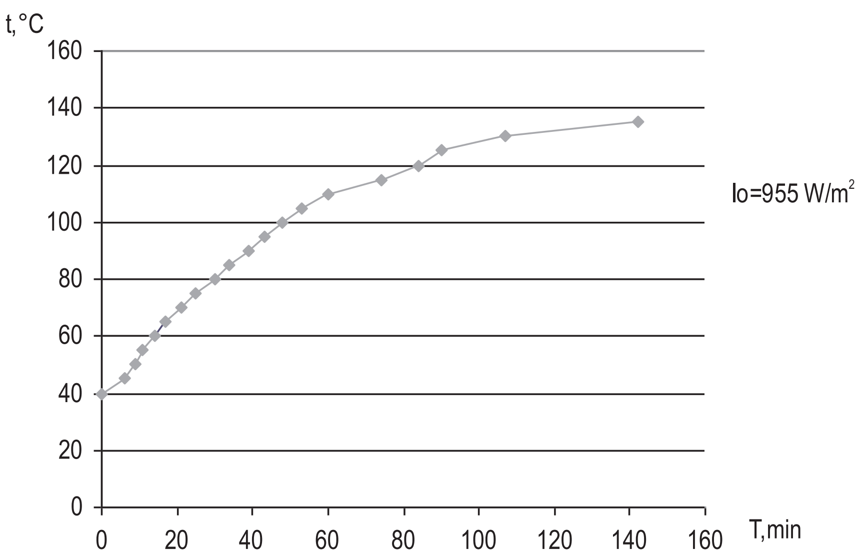


Figure 6. Graph of temperature changes of the heat agent in the thermal collector module at mounting angle α=40° (Io – solar radiation intensity, W/m^2).

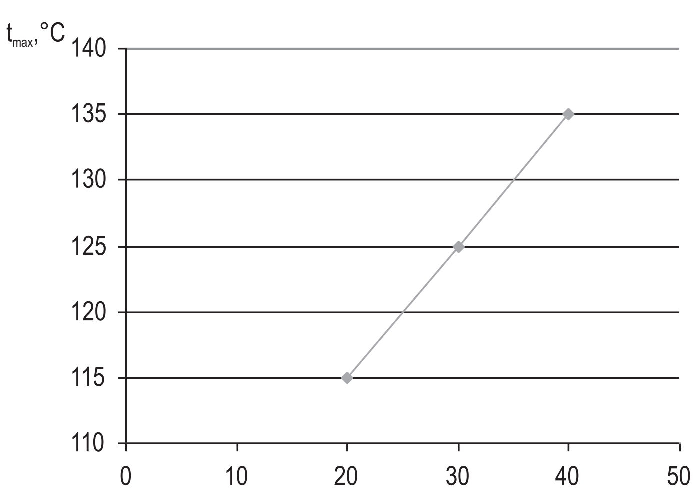


Figure 7. Graphical interpretation of the relationship between the maximum temperature potential of the heat agent in the solar thermal module and its mounting angle.

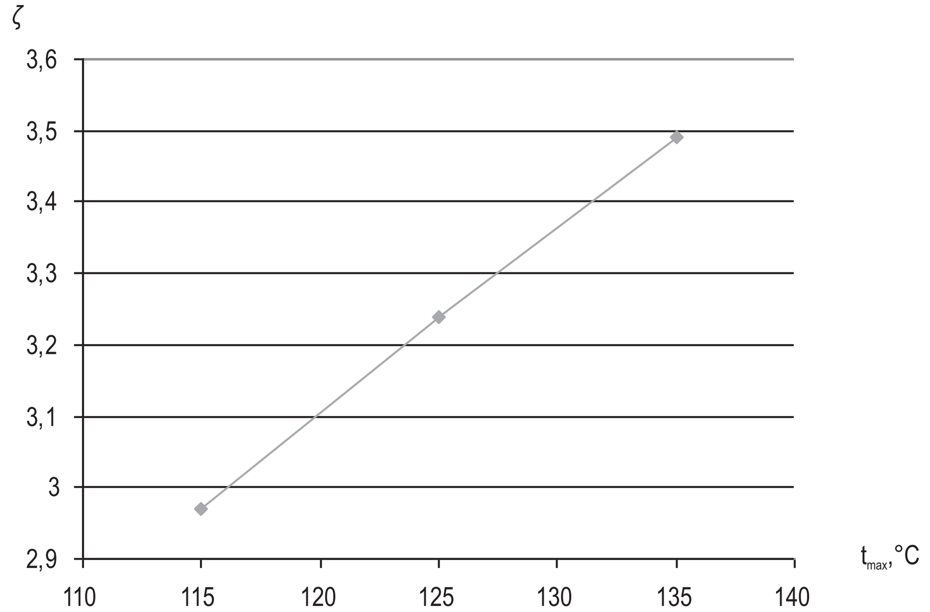


Figure 8. Graphical interpretation of the dependence of the theoretical heat coefficient on the temperature level of the heat agent in the solar thermal module.

difference was in the maximum temperature levels measured, respectively 125˚ C and 135˚ C. These values were obtained under the conditions of solar radiation average intensity Io = 955 W/m2 and ambient temperature of about 31˚ C. The reported maximums were registered respectively in the 115th and 140th minute from the start of measurements.

On the basis of the temperature potentials determined, ambient temperature and conditionally assumed evaporation temperature of refrigerant (T_o=10˚C), the calculated values of heat coefficient ζ were respectively 2.97 for a mounting angle of 20˚, 3.24 for 30˚, and 3.49 for 40˚. The magnitude of these values is a theoretical argument for the possibility of highly efficient thermal driving of a cooling (air conditioning) machine of the absorption type using the thermal energy of a solar thermal module at temperature levels 125-135˚ C.

The graph in Figure 7 describes the relationship between the maximum temperature potential of the heat agent in the solar thermal module and its mounting angle. Increasing the mounting angle α from 20˚ to 40˚ results in increase of registered temperature maximums from 115˚ to 135˚ C. The established relationship is of a defined linear nature.

Using the method of least squares, an equation for linear regression of the maximum temperature of the heat agent (t_{max}) on the value of the mounting angle (α) was derived:

$$t_{max} = 95 + \alpha, \ ^\circ C \qquad (6)$$

The equation obtained shows that changing the mounting angle of the solar thermal module with 1 degree angle (in the range of angle α = 20˚ - 40˚) will imply a change of maximum temperature of the heat agent with 1˚.

Figure 8 gives a graphical profile describing the dependence of the theoretical heat coefficient on the thermal level of the heat agent provided to power the absorption cooling (air conditioning) machine. A temperature rise of the heat agent results in an increase of the value of the theoretical heat efficiency which is indicative of a greater efficiency in the operation of the absorption machine.

Within the experimental range (115˚ -135˚) the established relationship is of linear nature. The equation for linear regression (using the method of least squares) of the theoretical heat coefficient on the temperature potential of the heat agent derived is:

$$\zeta = -0.017 + 0.026\, t_{max} \qquad (7)$$

Therefore, the increase in temperature level of the heat agent by 1˚ C in the range of 115˚ -135˚ C causes an increase in the value of the theoretical heat coefficient by 0.009.

The result from equation 7 gives reasons to give an applied recommendation regarding the design and construction solutions in the development of solar thermal modules intended for absorption cooling. Achieving high temperature levels for the heat agent in the thermal module is a guarantee for high efficiency operation of the absorption refrigeration machine.

Conclusion

The maximum temperature potential of a solar thermal module constructed on the basis of vacuum heat pipes (Heat Pipe type) is in the range of 115-135˚ C. The results refer to "a typical summer day" with ambient temperature about 30-32˚ C and average solar radiation of 950-970 W/m^2. 2. The temperature maximum of the heat agent in the solar thermal module depends on its angle. Increasing the mounting angle by 1 degree angle in the range of 20-40˚ leads to an increase in the temperature maximum of the heat agent by 1˚ C. The established temperature maximums and corresponding values of the theoretical heat coefficient ζ are a convincing argument for the possibility of thermal driving of an absorption refrigeration machine for air conditioning of animal raising buildings using solar thermal modules.

The heat coefficient describing the energy exchange in absorption refrigeration machines is highly influenced by the heat agent temperature levels. Increasing the temperature of the heat agent leads to an increase in the values of the heat coefficient ζ which ensures high efficiency operation of the absorption refrigeration machine.

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