SOLAR EQUIPMENT FOR PREHEATING BITUMEN

by

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This paper presents results of the research and development of the process for preheating bitumen using solar energy obtained at the Polytechnic University of Timisoara. The aim of the research was examination of the opportunity to use solar energy for preheating bitumen and to optimize connection between several solar collectors. Results of the investigation were tested in real industrial conditions by organizing slow process of the solar exposure in passive regime on the roof of the building where the bitumen is stored. In present paper laboratory installation using solar energy for heating bitumen in close to real conditions is described. The experimental results indicates an efficiency about of 25-30% and the temperature level of 54-57 °C. In second part of the paper the results obtained at the industrial installation for bitumen heating in large reservoir containing 30 t of material were analyzed. Paper is addressed to the specialists' aiming to extend use of solar energy in different fields of application.

Key words: *passive use of solar energy, solar heating, bitumen, warm-up, thermal efficiency*

Introduction

Modern production technology of the hydrocarbon pavement mixture consists of two phases: in first phase the bitumen is kept at the temperature smaller then 100 °C, and second phase starts when the necessary quantity of bitumen that has to be melted at 150 °C is ready to be inserted in the furnace.

The process of passive solar heating may increase bitumen temperature up to 60-80 °C. Analyzes of the physical and mechanical characteristics of the bitumen shows that it is reasonable to use solar energy for bitumen preheating.

The physical and mechanical characteristic of the TD type bitumen used in our climate zone for covering streets, are as follows:

- size of bitumen particles (at 25 °C), from 16 to 20 mm,
- softening temperature, 38-44 °C,
- elongation (at 0 °C), 9 cm,
- freezing temperature, break point, –25 °C, and
- density (at 15 °C), 1.0 g/cm^3.

Low softening temperature of the bitumen suggests possible use of solar energy for the bitumen preheating and melting, during manufacturing of the hydrocarbon pavement mixture.

There are practically no published results of the experiments devoted to use of solar energy for preheating of the bitumen. This is the reason why we can refer only on the research done in the Department of Physics, from Polytechnic University of Timisoara.

The solar laboratory installation for bitumen heating in passive regime is described in [1]. Bitumen temperature of approximately 56 °C can be obtained in this installation.

Characteristics of the passive solar receivers used in the laboratory installation are given in [2, 3]. Efficiency of the solar collectors for bitumen preheating was determined to be between 27-30% [2, 3].

Industrial size installation used to preheat 30 t of bitumen using passive solar heating is described in [4, 5]. Temperatures in the bituminous plate heated using solar energy are given in [6, 7].

The laboratory installation with cover made from semi cylindrical glass

The laboratory installation is shown in fig. 1. The cylindrical reservoir has the length $l = 0.30$ m, the diameter $d = 0.15$ m, and mass $m = 1.17$ kg, containing $M = 6.4$ kg of bitumen. The reservoir is oriented to south [1-3], and is inclined at 30° angle with the horizontal axis.

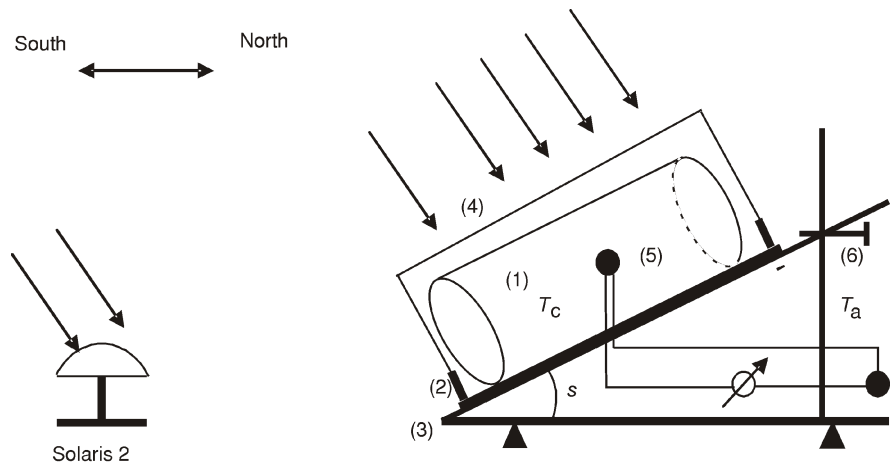

Figure 1. The installation with cover from glass semi cylindrical for the heating of the bitumen
1 – thin wall cylinder made from ferric metal, and painted in black, 2 – support for tire, 3 – support for reservoir made from insulating material, 4 – roof made from glass plates, 5 – thermometers for measurement bitumen temperature, T_c, and ambient temperature, T_a, 6 – device for changing angle of the cylinder axis with the horizontal plane

Temperatures were measured with the accuracy of $\Delta t = \quad 0.5$ °C. The intensity of solar radiation, I , was measured with the instrument based on an original concept developed by Department of Physics, and named Solaris 2, with the error range equal to $\Delta I = \quad 1$ W/m^2.

The temperature of the bitumen t_b, the temperature of the ambient t_a, and the intensity of solar radiation were measured during the daytime each 5 days in June – *i. e*. at 10th, 15th , 20th, 25th, and 30th of June. Average values of all parameters measured were calculated afterwards for the average day in June. For example, the average intensity of the solar radiation on an aisle and for one hour was determined according to the relation:

$$I_k \qquad \frac{1}{q\Sigma I_{ki}} \tag{1}$$

In relation (1), q is the number of days ($q = 6$), while k indicates the number of measurement during the day.

Bitumen temperature t_{bk}, ambient temperature t_{ak}, and solar radiation intensity I_k, measured during one day according to the timetable are shown in tab. 1. Temperature of the bitumen reaches value up to 56.5 °C at 4 p. m. The temperature increase from initial temperature is $\Delta t_d = \Sigma\Delta t_k$, $\Delta t_k = t_{k+1} - t_k$, $\Delta t_d = 35.5$ °C (see tab. 1). The amount of heat used during the day for bitumen heating, Q_{ud}, calculated for the maximal temperature (at 4 p. m.), is calculated according to:

$$Q_{ud} = (MC_b + mC_{Fe})\Delta t_d \tag{2}$$

In relation (2), C_b represents specific heat capacity of the bitumen, while C_{Fe} is specific heat capacity of the reservoir, and Δt_d is the increase of the bitumen temperature. The heat capacity of the bitumen and reservoir is $CC = MC_b + mC_{Fe} = 7.81\cdot10^2$ J/K.
Thermal power of the collector, P_c is:

Table 1. The values timetables size: t_{bk}, t_{ak}, I_k, I_d, p, and η, measured during one day according to the prescribed timetable

Hourly interval $\Delta\tau$	08-09	09-10	10-11	11-12	12-13	13-14	14-15	15-16	16-17	17-18	18-19
t_{bk}	21.0	24.5	30.0	36.0	42.5	47.5	50.5	54.0	56.5	56.5	53.5
t_{ak}	18.5	19.5	21.0	24.5	26.5	28.5	30.0	32.5	32.5	31.0	28.5
I_k	344	438	760	863	978	960	747	684	431	386	297
p	213.77										
I_d	721										
η	29										

$$P_{c} \quad \frac{Q_{ud}}{\tau} \tag{3}$$

In relation (3), τ [s] is time for preheating bitumen, $\tau = 3600n$, where n is the number of the hours during which the heating has occurred ($n = 8$).

The specific thermal power of the collector, p, is:

$$p \quad \frac{P_{c}}{A_{c}} \tag{4}$$

In relation (4), A_c is axial cross-area of the main reservoir, $A_c = ld$, $A_c = 4.5 \cdot 10^{-2}$ m^2.

The average intensity of the diurnal radiation incidents on collector, I_d, was calculated using formula:

$$I_{d} \quad \frac{1}{n\Sigma I_{k}} \tag{5}$$

and the efficiency of the collector was calculated as:

$$\eta \quad \frac{p}{\langle I_{d} \rangle} \tag{6}$$

The values of the parameters p, I_d, and η are presented in tab. 1.

For the conditions described, the efficiency is approximately 29% and specific thermal power of the collector is 213.77 W/m^2.

The optimization of the position of solar collectors for region Romanian West

The passive collector at a constant inclination is not able to accomplish the conditions of maximum solar irradiation. Calculation of the optimum angular range for the flat plate solar collector inclination oriented toward south is shown in tab. 2 for different periods of the year [8].

Table 2. The angular range and the number of the supply hour for flat plate solar collector oriented toward south [8]

Season	Months	Inclination of the solar collector against the horizontal plane, s	The number of the supply hour and the time interval
Winter	Dec. 20-Feb. 20	50-70	6 (time of day 9-15 h)
Spring and autumn	Mar. 20-Jun. 21	30-60	7-10 (time of day 7-14 or 7-17 h)
Summer	Jun. 21-Sep. 23	20-30	10-11 (time of day 7-18 h)

The above values were determined considering that 2 hours of supply, I/I_0 0.5 the lifetime will be maximal (I_0 – solar flux density, I – incident flux density on the collectors). The roof of the existing buildings has an inclination s in the range of 20-60°.

Industrial equipment for solar preheating of bitumen in Sacalaz Timisoara

The main design of the industrial equipment for solar bitumen preheating built in Sacalaz is presented in fig. 2. The solar collectors were placed on the roof of the existing building. The technical restrictions determined by construction of the building allowed only preliminary measurements. Using the solar energy for the bitumen preheating was possible since the construction on the roof offered the option to place solar collectors with an active surface of about 300 m^2.

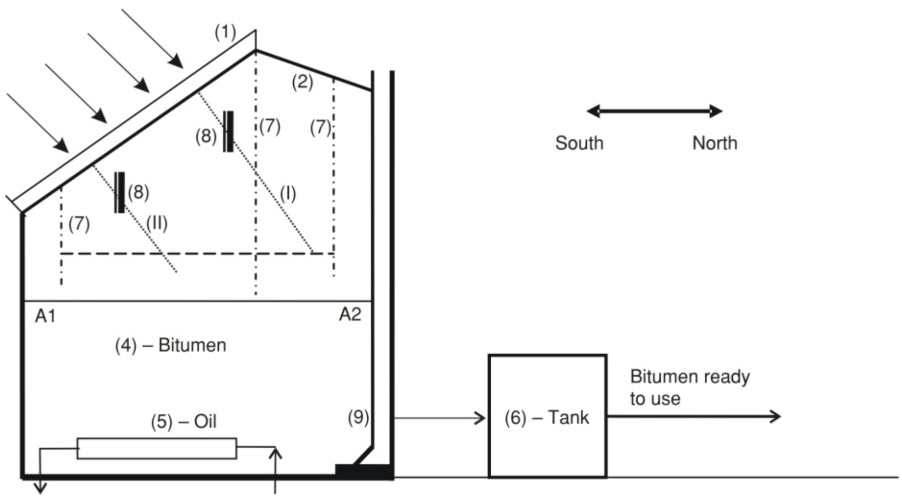

Figure 2. The scheme of the industrial installation for solar preheating of the bitumen
1 – solar thermal collector, 2 – roof made from the black plates, 3 – pipes inserted in bitumen, 4 – compartments filled with bitumen preheated at 90-100 °C, 5 – oil heat exchanger, 6 – tank for final bitumen heating up to 100-150 °C, 7 – metallic sheets placed at 0.5 m distance, 8 – thermometers, 9 – oven, 10 – (I) and (II) – lines that lie at 90° angle with the surface of the roof, 11 – A1-A2, free surface of the bitumen

In fig. 2 cross-section of the building and position of the solar collector are presented. On the black surface of the roof, at the distance of 0,75 mm, glass layers have been mounted to produce green house effect.

The parts of the industrial installation is shown in fig. 2.

In fig. 3 the details of method for mounting and assembling glass plates and metallic plates on the roof of the building (of the hall) with bitumen, are shown.

Conventional technology for bitumen treatment consists of two stage heating. In the first stage bitumen is preheated using hot oil flowing through the oil heat exchanger (5) (fig. 2). Additionally, a hot combustion product from oil burning flow through vertical pipes (3), and the bitumen is consequently heated up to 90-100 °C. The second stage is carried out in the tank (6), where bitumen is further heated up to 150-170 °C.

The solar installation is designed to preheat bitumen up to 50-55 °C by solar energy, resulting in adequate saving of the fuel consumption.

During measurements and testing of the solar industrial installation, conventional heating installation was shut down.

Experimental procedure: thermocouples were places along two lines, (I) and (II), perpendicular to absorbing surface. Those lines were set at the distance 1.5 m from the top and 3.5 m from the base.

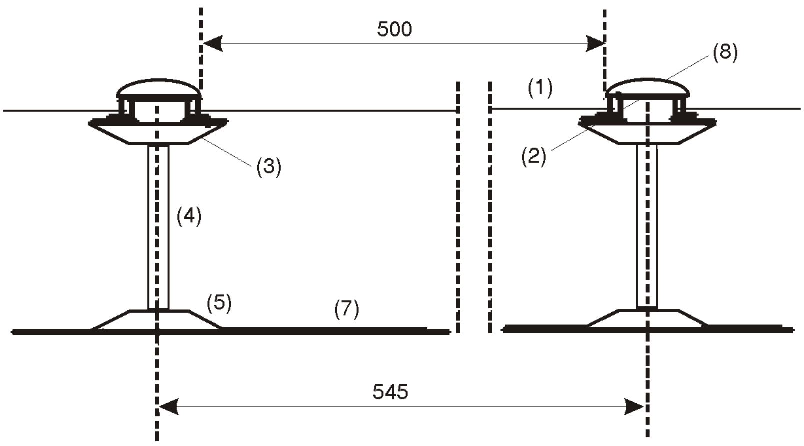

Figure 3. The system of assemblage of plates on roofs
1 – glass plates, 500 1000 mm, with a thickness of 5 mm, 2 – corner holder, 60 40 25 mm, 3 – rubber layer, 4 – steel profile I12, height L = 100 mm, 5 – support, 6 – roof wooden plate, thickness 0.75 mm, 7 – black color with extra oxide 200 g/kg, 8 – concrete steel reinforcement rod, 6

Figure 4 presents the temperature distribution at different distances along the lines I, t_{IhD}, and II, t_{IIhD}, for random hours of our choice during one sunny day:

$$\left\langle t_{\mathrm{hD}} \right\rangle \quad \frac{t_{\mathrm{IhD}} \quad t_{\mathrm{IIhD}}}{2} \tag{7}$$

In relation (7), D is the distance between the absorbing surface and measurement point along lines (I) or (II) (fig. 2).

Then, the average temperature was calculated for each hour according to:

$$t_{\mathrm{k}} \quad \frac{1}{r\Sigma t_{\mathrm{hD}}} \tag{8}$$

In relation (8), r is the number of measurements along the lines (I) and (II), $r = 12$. The values of the temperature t_a and t_h are shown in tab. 3.

Table 3. The average temperatures in the solar trap

Time of day	9 h 30 min.	10 h 30 min.	12 h 30 min.	14 h 30 min.	16 h 30 min.	18 h 30 min.
t_a	27.5	28.5	34.0	35.0	33.5	31.0
t_h	38.0	47.5	55.5	56.5	55.0	52.5

The temperature distribution at randomly selected hours during the day (presented in fig. 4), shows:

– at dawn, the temperature near the roof is significantly lower than the temperature near the free bitumen surface,
– from about 10 h a. m., the temperature near the roof becomes higher compared to the temperature near the free surface of the bitumen, and
– the temperature distribution lines will obtain the inflexion point. The position of the inflection point moves slowly during the day towards the larger distances from the roof.

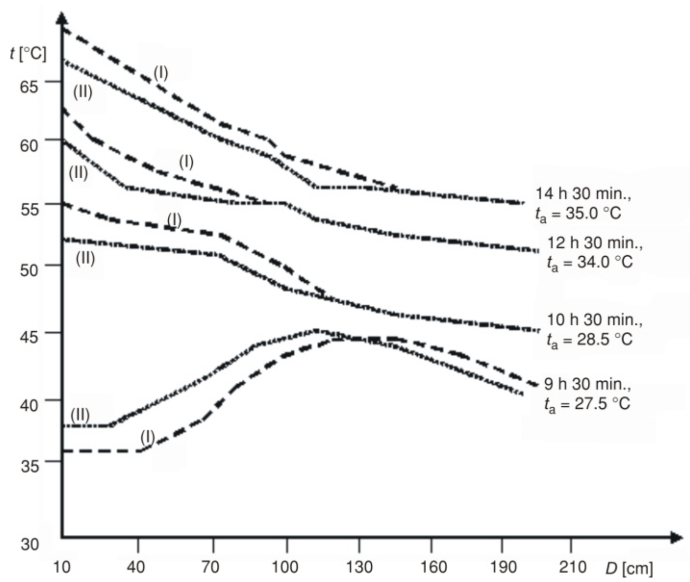

Figure 4. The variation of t_{I} and t_{II} during the day and at different distances from the roof

Variation of the time average temperature t_h , at the distance from the roof, D = = 1 m, and ambient temperature t_a are shown in fig. 5. The temperature measurements presented in tab. 3 show the following:

– the temperatures reach maximum values at 14 h 30 min.,
– the maximum average temperature along the lines is 54-56 °C, and
– the ambient temperature is 27-35 °C.

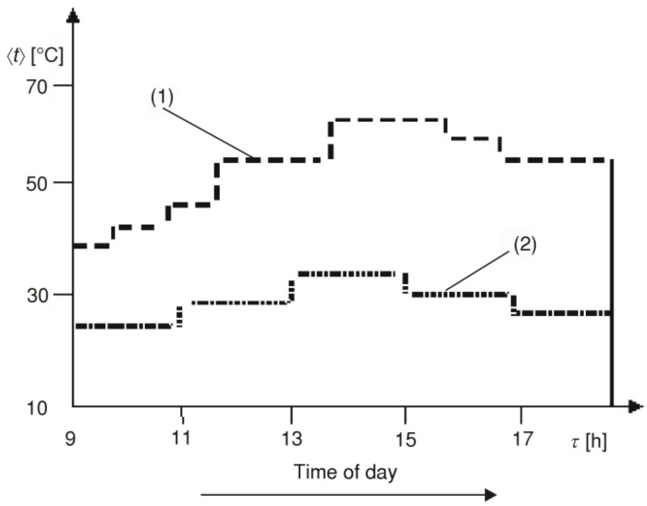

Figure 5. The variation of 1 – time averaged temperature $t(\tau, 1)$, at the distance from the roof D = 1 m, and 2 – ambient temperature $t_a(\tau)$ during the measuring day

Conclusions

The tanks for bitumen storage can be supplied with solar thermal collectors witch can save significant amount of fuel necessary to heat up bitumen during preparation for farther use. The estimated savings of the fuel are about 80 kg/year for each 1 m^2 of solar collector placed on the storage building roof.

The investigations of the industrial and laboratory installation for solar preheating of the bitumen have shown:

– the maximal efficiency of the equipment used for preheating bitumen is obtained during the sunny days, with solar collectors set along the northern-south line (possible discrepancy from this line can be tolerated to be 15 degrees),
– the laboratory installation successfully operated when the bitumen storage tank containing 6 kg of bitumen was set at 30° angle with the horizontal plane,
– during summer the temperatures of the bitumen exceeded by the ambient temperature by 30 °C, while in the laboratory installation bitumen temperature reached 56.5 °C,

- during nighttime there is a change of the temperature range as a consequence of the heat flow from upper zones towards downward,
- in order to reduce the heat quantity necessary for bitumen melting it is recommended that the bitumen extraction should not be organized later than 3-4 h p. m., and
- the vertical metallic grids places between the absorbing surface at the roof and free surfaces of the bitumen intensify heat transfer from the roof to the bitumen surface.

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Nomenclature

A	– surface area, [m^2]
A1-A2	– the free bitumen surface, [–]
C	– specific heat capacity, [$JkgK^{-1}$]
(CC)	– heat capacity, [JK^{-1}]
D	– distance between the absorbing surface and measurement point, [m]
d	– diameter, [m]
I	– intensity of solar radiation, [Wm^{-2}]
(I), (II)	– lines orthogonal to absorbing surface
l	– length, [m]
m, M	– mass, [kg]
n	– number of measurements during day, [–]
P	– thermal power, [W]
p	– specific thermal power, [Wm^{-2}]
s	– inclination angle, [grad]
Q	– heat quantity, [J]
q	– number of days, [–]
T	– temperature, [K]
t	– temperature, [°C]

Greek letters

Δ	– finite difference
η	– efficiency
τ	– time, [h or s]

Subscripts

a	– ambient	Fe	– iron
b	– bitumen	h	– hourly
c	– collector	k	– index
D	– distance	u	– useful
d	– diurnal		

Mathematical operator

– average

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