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ASPHALT PAVEMENT AND ENERGY COLLECTION

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ABSTRACT

Romania, as an EU member state is bind to appraise and disseminate accurate and updated information about quantities, types, sources, production, transformation and consumption of energy in order to monitor the impact and consequences of its energy policy. Energy statistics, traditionally focused on energy supply and fossil energy, need to be developed in order to ensure better knowledge and monitoring of renewable energy sources, according to targets set by Directive 2009/28/EC. So far, In Romania, no one has been interested in putting into practice this idea and there has been no study in this respect. This paper aims at conducting laboratory experiments on samples similar to asphalt structure deposited over the public roads in Romania, for energy recovery.

KEYWORDS: energy, efficiency, asphalt, recovery

1. Introduction

Of all land passageways, roads have their beginnings in ancient times, being for thousands of years the only means of communication between people, for their own movement and transport of goods among inhabited areas. From antiquity until today, roads have developed differently depending on both economic and social levels and also on the degree of civilization of each era.

The emergence of the motorcar will lead to a new boom in road engineering, increased number of motor vehicles, directly affecting the design, construction and maintenance of roads. Human life cannot be conceived but dynamically in space and time, the need to move to ensure existence being an essential component of an organized society. This, in its evolution, has always needed communication routes as intrinsic mediator of trade, cultural, goods or persons exchanges.

Romania has a high attractiveness for investments in road infrastructure and implementation of techniques and solutions for generating thermal energy accumulated in roads and highways covered with asphalt.

2. Objective

This paper aims at conducting laboratory experiments on samples similar to the road asphalt coat structure for the study of the heat exchange and accumulated thermal energy recovery. To exploit the heat energy of the asphalt, it is proposed to place water - filled metal pipelines under the asphalt. The water in the pipes receives the heat accumulated in the asphalt and can be further used in a heat exchanger to supply hot water for domestic use offices, industrial areas or can be converted into electricity.

Asphalt road construction materials are used to provide a road coat able to bear the burden of road traffic vehicles and transfer it in a dispersed form to the road foundation/base [1].

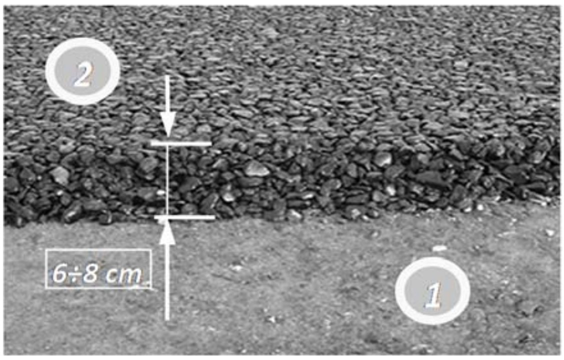


***Fig. 1**. Base and link layers[1]*
1-ballast foundation; 2-asphalt mixture

The main types of construction materials are binder and aggregates. (Fig.1). Depending on the binder used, road layers are classified as rigid (cement) and flexible (bitumen). The running layer 1 of the asphalt road structure is composed of bitumen

(5÷10%) and granular mineral aggregates (gravel, quality rock, sand).

Energy generated by the sun is the most important and reliable resource of all renewable energy sources currently exploited. This also represents an inexhaustible source of energy for humans, especially due to its energy being clean, uncontaminated. The solar radiation reaches the Earth's surface as direct solar radiation and diffuse solar radiation due to Earth's atmosphere.

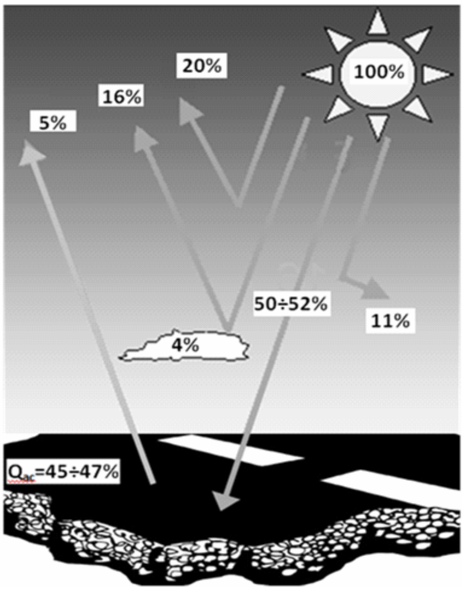


Fig. 2. *Distribution of solar radiation*

The global radiation received from the Sun, on a horizontal surface at ground level on a cloudless day, consists of the sum of the two radiations. Absorbed radiation is generally converted into heat and diffuse radiation is returned to all directions in the atmosphere (Fig. 2).

The reduced temperature will extend the life of the pavement, while the reduced temperature of the near surface air will lead to savings in energy consumption of adjacent buildings and improvement in air quality (such as by reducing ozone concentration).

3. Working method

Samples were made in wooden boxes (Photo 1) by depositing successive layers of materials while complying with the quality and height requirements. Between the base layer and the granular mineral aggregates, a metal coil (Photo 2) was covered with asphalt (Photos 3, 4).

Photo 1.
Box manufacturing

Photo 2.
Coil location

Photo 3, 4. *Laying the asphalt coat*

In the laboratory, the asphalt samples were exposed to heating by a radiator (Photo 5) fitted with a variable voltage device so that it could be established a steady temperature by loss compensation. Water in the system is circulated through the metal coil located under the carpet of asphalt and a buffer tank by a pump driven by an electric motor controlled by a thermostat (Photo 6).

Photo 5
Electrical heater

Photo 6
Water buffer tank

The temperatures T_1 - at the sample surface (Photo 7), T_2 - at 5 cm depth into the asphalt (Photo 8), and T_3 - the water temperature (Photo 9) in the buffer tank were measured from the beginning of asphalt heating until stationary temperature was reached.

Photo 8, 9. *Location of thermometers*
Asphalt surface *Water tank T3*

4. Laboratory measurements

Transport of the accumulated heat energy in the asphalt layer to the coil is carried out by conduction and, from the coil wall to the water circulated by a pump to the buffer tank (active system), by convection.

After establishing a steady temperature between the heat emitted by the radiator and the heat accumulated in the asphalt sample at a distance of 30, 35 and 40 cm (so that the surface temperature be constant) temperatures T_2 and T_3 are measured at intervals of about 30 minutes until the water temperature remains constant.

Table 1. *Notations and calculation relations*

Denomination	Symbol	Value	Measure unit
Distance from resistance to asphalt surface	H	$(35, 40, 4)\cdot10^{-3}$	[m]
Thickness of asphalt layer, (Photo 4)	x	Measured = $50\cdot10^{-3}$	[m]
Coil diameter	d_s	Measured = $5\cdot10^{-3}$	[m]
Coil heat exchange surface	s_s	Calculation = $6.863\cdot10^{-3}$	[m^2]
Asphalt surface	S_{asf}	Calculation = $2.925\cdot10^{-3}$	[m^2]
Asphalt volume	V_{asf}	Calculation = $0,146\cdot10^{-3}$	[m^3]
Thermal conductivity [8], [9]	$\lambda_{asph.}$	0.75÷0.9	W/(m.K)
Density [8], [9]	$\rho_{asph.}$	2640	Kg/m^3
Specific heat capacity [8], [9]	$c_{asph.}$	385	J/(kg.K)
Resistors voltage	U	Measured = 220	[V]
Intensity of resistance current	I	Measured = 1,88	[A]
Resistor temperature	T_R	Measured = 1100	[^{0}C]
Ambient temperature	T_0	Measured = 15	[^{0}C]
Stefan Boltzmann's constant [8]	σ_0	$5.67\cdot10^{-8}$	W/(m^2.K^4)

5. Calculation of heat exchange efficiency

Resistor radiation (t=1hour):

$$Q_{rez} = U \cdot I \cdot t = 413.6\,[Wh] = 1488960\,[J] \quad (1)$$

Heat transmitted by radiation:

$$Q = \varepsilon_{red} \cdot \sigma_0 \cdot \left[(T_{rez})^4 - \left[(T_1)^4 \right] \right] s_{box} \cdot 3600\,[J] \quad (2)$$

The transfer of energy by electromagnetic waves through empty space is called radiation heat transfer. Energy can be transferred by thermal radiation between a gas and solid surface or between two or more surfaces [9].

Heat transmitted by conduction from the asphalt:

$$Q_{c,asph} = \frac{\lambda}{x} \cdot (T_1 - T_2) \cdot s_{box} \cdot 3600 \quad [J] \quad (3)$$

The heat transfer by conduction is the energy transfer through a substance, a solid or a fluid as result of the presence of a temperature gradient within the substance [9].

Heat accumulated in asphalt:

$$Q_{c,asph} = m_{asph} \cdot c_{asph} \left(\frac{T_1 + T_2}{2} - T_0 \right) \quad [J] \quad (4)$$

Heat flow transmitted by convection:

$$Q_c = \alpha_c \cdot (T_2 - T_3) \cdot s_s \cdot 3600 \quad [J] \quad (5)$$

The heat transfer by convection is the energy transfer between a fluid and a solid surface. Heat transfer by convection is more difficult to analyze than the heat transfer by conduction because it varies from situation to situation upon the fluid flow conditions. In practice, the heat transfer by convection is treated empirically [9].

Heat amount from the water (m_a = *4kg*) in the vessel:

$$Q_{water} = m_w \cdot c_w \cdot (T_3 - T_0) = 231012 \quad [J] \quad (6)$$

Exchange output/efficiency:

$$\eta = \frac{Q_{rez}}{Q_{water}} \cdot 100 = 15.51\,\% \quad (7)$$

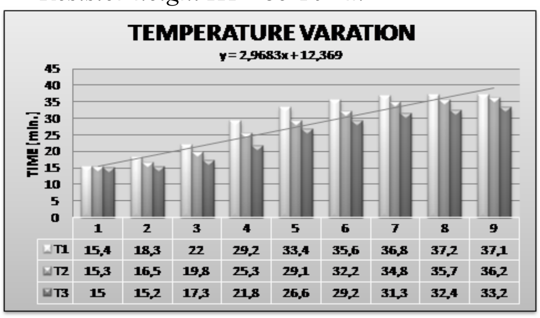
Efficiency is calculated 15.51%, large losses of approximate 35% are produced by convection from the radiator to sample asphalt. The efficiency of the pavement ‐ heat exchanger system in transmitting the heat from the pavement to the fluid inside the system of pipes depends on a number of factors, including:

1. The pavement surface actually collects the incident solar radiation. If it is a highly reflective surface (high albedo) then very little heat will be absorbed and be available for harvesting. If on the other hand, the absorptivity is increased (say by painting the surface black), then we will have more heat energy to harvest.
2. The function of the pavement materials depend on their location with respect to the heat exchanger system. For the materials in the layers above and around the heat exchanger system, the ideal function should be to transmit the heat (or conduct the heat, more approximately) in the most efficient manner. The function of the materials in the layer beneath the heat exchange system should be to insulate the system from the bottom layers, such that very little heat can be transmitted through the bottom layers.
3. The material of the heat exchanger system (which consists of pipes) should have a high conductivity and the layout should be such as to allow the exposure of the pipes to the pavement for sufficient length to allow the fluid to reach the maximum temperature achievable in the system.
4. The initial temperature of the fluid (that is the temperature of the fluid as it enters the heat exchanger system) should be low enough, in comparison to the temperature of the pavement, such that the there is significant difference between the two, and hence a significant rate of flow of heat into the fluid.

6. Measured values

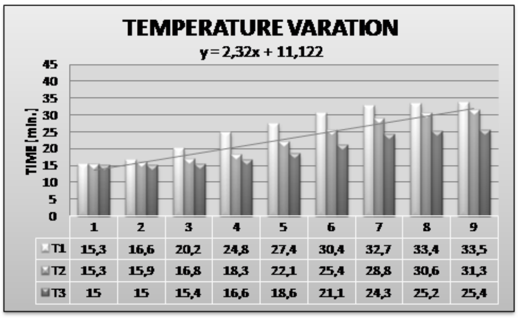
Based on measurements made over 2 hours and in three different cases, with variations of radial distance and sample asphalt (H), the results obtained were presented in Tables 2÷4.

Resistor height H1 =35·10^{-3} m



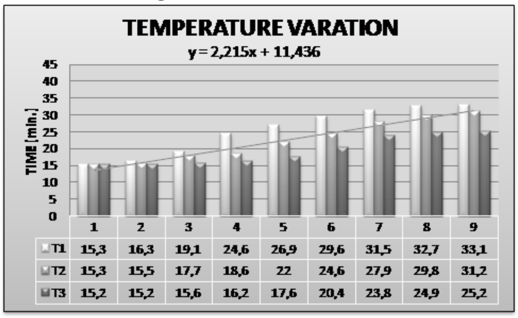
Graphic 1. *Heating up to the stationary temperature H1*

Resistor height H2=40·10^{-3} m



Graphic 2. Heating up to the stationary temperature H2

Resistor height H3=45·10^{-3} m



Graphic 3. Heating up to the stationary temperature H3

These were processed in resulting graphs with a linear variation of temperature in the three points T_1, T_2 and T_3.

The temperature at any depth of the pavement depends on the pavement materials and the surface temperature which, in its turn, depends on a number of factors including location, surface, wind speed and cloud cover.

Based on available models, pavement temperatures at different depths can be predicted throughout the year.

7. Conclusions

The road infrastructure in Romania is poor, which calls for major investments in this sector and development in the future.

The construction of public asphalt roads is based on the use of specific materials, such as binder and aggregates, deposited in successive layers.

The important cost considerations are those that are needed for the installation of the system –labor and materials, for piping and pumping, as well as for the end application (for example, a turbine, if the generation of electricity is required), and maintenance of the system. The payback period can be estimated by calculating the savings in energy consumption, and/or selling of excess energy to a grid.

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