Energy 135 (2017) 75–82

Contents lists available at ScienceDirect

Energy

journal homepage: www.elsevier.com/locate/energy

Influence of the sun exposure surface area of the solar aggregate stockpiles on the accumulated heat of the stored mineral mixture

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ARTICLE INFO

Article history:
Received 10 February 2017
Received in revised form
19 June 2017
Accepted 20 June 2017
Available online 21 June 2017

Keywords:
Solar aggregate stockpiles
Sun exposure
Energy
Hot mix asphalt production

ABSTRACT

This paper analyses the influence of the variable sun exposure surface area of the solar aggregate stockpiles on the results of the mineral mixture accumulated heat in different seasons (summer – autumn). The solar aggregate stockpiles in question are intended for use in industrial applications for the production of Hot Mix Asphalt (HMA). These tests aim to establish the difference in temperature of the mineral mixture with and without the effects of sunlight. For the purpose of this test, three test models of solar aggregate stockpiles and one reference model to simulate the conditions of uncovered and unprepared surface storage were constructed. All the solar models had consistent volumes, the same shape, thickness and type of brim heat insulation and orientation, where the only difference was the surface area of the glass opening designed to let through varying amounts of sunlight. For the purpose of this test, analysis was made of the heat build-up of the mineral mixture when exposed to sunlight, without exposure to sunlight at night, and the drop in temperature over several days when the mixture was not exposed to sunlight. The results of the test show that the increased opening area of the solar aggregate stockpiles and the use of solar models in themselves lead to increased heat accumulation of the mineral mixture and reduced heat loss during daytime and in other conditions when the mineral mixture is not exposed to sunlight.

1. Introduction

The process of manufacturing Hot Mix Asphalt (HMA), as well as the processes of other industrial branches, requires significant amounts of thermal energy. According to some estimates [1] it is expected that world energy consumption will grow by 48% between 2012 and 2040. Renewable energy is increasing by an average of 2.6% per year through to 2040 as one of the fastest growing energy sources over the projected period. The share of renewable energy resources of total energy use in the Republic of Croatia amounts to an acceptable 36.1% (EIHP method), or 24.8% (Eurostat method) according to data provided by the Annual Energy Report 2014 [2]. According to information from the World Energy Council, it is estimated that global average solar radiation, per m^2 and per year, can produce the same amount of energy as a barrel of oil or 200 kg of coal [3].

HMA contains stone mixture and dust, binder and additives that are mixed at a given equiviscous temperature. The mixing of the HMA components is performed at a viscosity of bitumen 170 ± 20 centistokes [4] which results in heating up the integral mixture components. The manufacturing process of asphalt mixtures is performed at continuous or batch asphalt plants with greatly varying costs depending on the location of the plant. From the manufacture analysis [5] it is evident that the average production of Warm and Hot Mix Asphalt in the Europe for the period 2008–2013 amounted to 307.1 million tons (ranging from 276.4 to 338 million tons). Fig. 1 shows an HMA production graph for the period from 1994 to 2007 for selected countries [6].

The highest total production of asphalt mixture in the observed period was in the USA (Fig. 1), amounting to 6933 million tons (495.2 million tons on average annually) which is 2726 million tons more than European production. According to some authors, the process of drying and heating the mineral mixture during the production of 1 ton of asphalt mix requires approximately 85 kWh of energy [7,8]. The authors [9] in their research state that in the course of 2007, the whole industry of

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http://dx.doi.org/10.1016/j.energy.2017.06.124

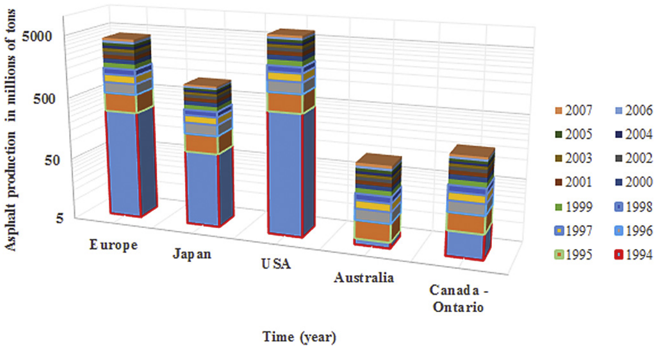

Fig. 1. The manufacture of hot mix asphalt.

HMA consumed roughly 0.3% of the total world's crude oil production.

1.1. Factors influencing energy consumption in the production process

Energy consumption in the production process of HMA (Fig. 2) are affected by the conditions of production and the storage of the mineral mixture (I), the moisture content and temperature range of the heated mineral mixture (I. a), the quality of the mineral mixture (I. b), the asphalt plant (II) and the type of the produced asphalt mixture (III).

The conditions of production and storage of the mineral mixture are directly related to the moisture content and quality of the mixture (Fig. 2). Certain authors [10–14] show the considerable influence of the moisture content (I. a) of mineral mixtures on energy demand. From research so far, it can be estimated that to dissipate 4% of moisture from mineral mixtures during the production of 1 ton of HMA requires around 30 kWh of energy. Ang et al. [10] report that reducing the moisture content by 3% leads to energy savings of 55–60% [10]. Jenny [13] also analyses the effects of moisture content on energy consumption and concludes that it requires around 0.75 kg/t of fuel to dissipate 1% of moisture [13]. Peinado et al. [9] reports a requirement of 8.21 kWh of energy to dissipate 1% moisture from the mineral mixture [9]. A compelling finding for the present study showed that reducing the heating temperature of the mineral mixture helps to lower energy consumption. As a result, some studies advocate using Warm Mix Asphalt which requires lower production temperatures [15–21]. Jenny [13] claims that lowering production temperatures from 180 to 115 °C during the production of asphalt can lower energy consumption by 1.5 kg per ton [13].

From the research results so far, we can establish that mineral mixture exposure to weather conditions plays a major role in energy consumption during the production of HMA. Considering that for the production process of HMA it is necessary to dry and heat the mineral mixture (which makes up over 90% of asphalt content) to the required temperature, there is a strong need to:

- lower the moisture content in the mineral mixture;
- pre-heat the deposited mineral mixture before use.

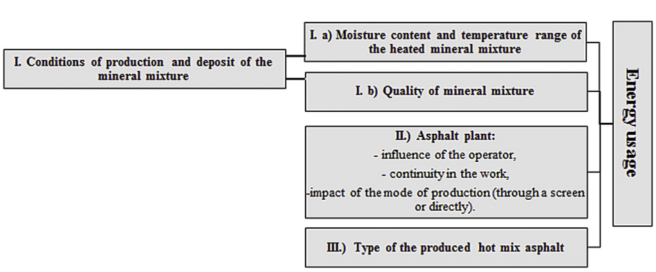

Fig. 2. Factors influencing energy consumption.

1.2. Potential ways of lowering the effects of weather conditions on the storage of the mineral mixture

In order to lower the moisture content in the stored mixtures, some research advocate that mixtures need to be stored in specially prepared and covered storage tanks [22–27]. This is accomplished in phase 1 (Fig. 2). To pre-heat the stored mineral mixture, it is necessary to achieve the highest possible heat accumulation from an outside source and to prevent heat loss to the atmosphere. Androjić and Kaluđer [28] consider the potential use of different models of solar stockpiles intended for storing stone fractions in the production of HMA [28]. The constructed models are made with a constant volume capacity, a thickness of thermal insulation of 2, 5 and 10 cm, and a glass ceiling surface. The primary goal of the built models is to attain high thermal energy accumulation from solar radiation during the exposure period of the mineral mixture.

Some of the main conclusions of the conducted research [28] are:

- the temperature of the mineral mixture in insulated models continually increases during exposure to solar radiation;
- increasing the thickness of the thermal heat insulation and the temperature leads to quadratic function dependency with very high R^2 coefficients of determination;
- during times without the effects of sunlight (night time) there is an exponential loss of accumulated thermal energy from the insulated models in contrast to the non-insulated storage tanks and other methods.

In order to analyse the effects of the preheated mineral mixture on energy requirements for drying, equation (E_{dry}) is used [10]:

$$E_{dry} = M_a(W/100)(70C_P + C_l) + M_a(70C_a), \quad (1)$$

where is Ma - total mass of mineral mixture, W –aggregate moisture, C_P - specific heat capacity of water, C_l - latent heat capacity of water and Ca - heat capacity of aggregate. The constant (70) represents the temperature range for heating the mineral mixture and moisture in drying the aggregate. The preheated mineral mixture of the solar stockpile affects changes in the temperature coefficient (70) by lowering the values. Potential energy savings can be achieved by preheating the mineral mixture as a result of moisture evaporation from the mixture at increased input temperatures.

1.3. Research goals

The experimental part is the continuation of research conducted by Androjić and Kaluđer [28] on the potential applications of solar aggregate stockpiles for mineral mixtures exposed to real-life weather conditions [28].

The primary goal of the research is to determine the effects of varying sun exposure surface area of the solar aggregate stockpiles on the accumulated thermal energy from summer to autumn. The research aims to establish the temperature of the mineral mixture in periods with and without the effects of solar radiation.