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Managing Thermal Energy of Exhaust Gases in the Production of Asphalt Mixtures

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Abstract: Production of construction material is energy demanding and connected with present environmental issues. Hot-mix asphalt production is no exception. For many years, asphalt industry has been trying to find the balance between dynamic fuel market and possibilities of improving the production process to reduce costs incurred by technology development. The development progress relies on careful assessment of the production process in order to find every possibility that may contribute to energy conservation. Many interventions have been successful in rationalizing energy consumption, but today's challenge is to go further in developing a production process that is more environmentally friendly and acceptable in terms of energy consumption. Proposed research and preliminary results are a contribution to establishing a model that describes the relationship of reducing moisture content and increasing the temperature of mineral mixtures by using the heat of exhaust gas in a short-term drying process. The proposed model could enable optimization of the technological process of production of asphalt mixtures and contribute to the implementation of technical innovations in hot-mix asphalt production.

Keywords: aggregate moisture content; drying process; energy demand; exhaust gas; HMA production

1 INTRODUCTION

The energy saving strategy in the construction sector should be seen in the context of the EU's energy and ecological commitment, aimed at fulfilling the energy and climate objective 20-20-20. Ever stricter ecological requirements as well as the aspirations for achieving significant energy efficiency savings in production processes have stimulated the need for analysis of the asphalt mixture production process in stationary asphalt plants [1]. In asphalt plants, energy sources (mostly fossil fuels and electricity) are needed for bitumen heating, drying and heating of stone materials, exhaust fan operation, plant operation and control room operation. Manufacturers of asphalt plants and asphalt mixtures deal with the problem of how to dry the aggregate more easily and economically. Possible solutions are predominantly focused on increasing the dimensions of the rotary dryer, designing larger burners or developing complex combustion solutions. Among the current drying technologies (tunnel dryer, furnace, disk dryer, atomization, flash dryer, fluidized bed), the rotary dryer is the one most commonly used in asphalt production [2].

During the production of hot asphalt mixtures, there is considerable energy consumption as well as unfavourable environmental effects. Energy consumption in the process of drying and heating the mineral mixture is in the range of 70-100 kWh (85 kWh) per tonne produced and 5-8 kWh in transport and storage of asphalt mixtures, releasing 22 kg of CO_2 [3, 4]. Factors affecting the consumption of energy sources in the production of asphalt mixtures are discontinuous production, utilization of the plant's production capacity, composition of the deposited mineral mixture and its exposure to weather conditions, production of asphalt mixtures in adverse weather conditions (period of lower air temperature and heavier precipitation), quality of energy sources used and the technological possibilities of the plant. Jullien et al. [5] indicate that up to 97% of the energy of the asphalt plant in operation is used for heating and drying of stone aggregates. Ang et al. [6] have proved, in a study conducted during the production and in the laboratory, that the aggregate moisture content has a crucial impact on energy consumption in the production of hot asphalt mixtures. According to the same study, it was suggested that the reduction of moisture content in the mineral mixture by 3% results in savings in energy consumption of 55-60%.

World experience suggests that proper construction of roofed and protected stockpiles of stone material can achieve significant savings of energy sources needed for drying and preheating stone materials [7].

The authors Grabowski and Janowski [8] report that the process of drying 1 t of mineral mixtures with a moisture content of 6% requires 4 l of fuel (heating oil), while an additional amount of 3 litres of fuel is required to heat the dry mixture to 150 °C. Grabowski et al. [9] indicate in their research that the production manager has a direct impact on the level of production as well as on energy consumption in the production of hot asphalt mixtures. Jenny [10] suggests that reducing the moisture content by 2% in the mineral mixture results in fuel economy savings of 1.5 kg/t of asphalt mixture. According to Peinado et al. [11], the required heat energy to raise the asphalt mixture temperature by 10 °C is around 2.62 kWh, while removal of 1% of the moisture content means an additional energy requirement of 8.21 kWh. In the investigations conducted by Androjić and Dolaček-Alduk [12] it was found that by removing 1% of the moisture content in the mineral mixture, they achieved energy savings of 13.13% and 4.51% in material heating (depending on the inlet temperature of the mineral mixture, 8 and 30 °C) thereby reducing the need for its warming.

An overview of the current research and conclusions made so far indicate a focus on determining the influencing factors in energy consumption in the process of drying and heating of the mineral mixture. Recent research in the achievement of energy savings in the process of asphalt mixing has included reducing the mixing temperature of the components of the asphalt mixture, the removal of moisture from the composition of mineral mixtures and the use of a high proportion of recycled material in the production process.

In this paper, preliminary results of the research will be presented pertaining to the possibility of removing some of the moisture from the composition of the mineral mixture by convection drying of the stone material on the conveyor belt, thus affecting the consumption of energy for drying and heating the mineral mixture in the rotary drum. For the drying of stone material, the use of the exhaust gas heat potential is proposed as an energy source in the drying process, the temperature of which, at the outlet of the chimney of the asphalt plant, is about 80 °C.

2 POSSIBILITIES OF APPLYING EXHAUST GAS HEAT IN THE PRODUCTION OF ASPHALT MIXTURES

The Republic of Croatia is faced with an increase in consumption and energy prices, which is accompanied at the same time with reduced availability of conventional energy sources. Compared to most Western European countries, Croatia uses energy less efficiently: we currently spend 16.5% more of primary energy per unit of GDP than it is the case with average EU spending [13]. Analysis of the existing situation has shown that in the segments of transformation and final use of energy, for example, in construction, among other things, there is still insufficient use of technical and technological innovations in this area. The dynamics of globalization requires all countries, including ours, to invest more financial and human resources in innovation and education, both in the public and private sector.

Nowadays there is a significant increase in prices of all types of energy sources, and consequently, any kind of savings or reduced demand for oil and natural gas on the part of large consumers such as the asphalt industry, is a tremendous success at all levels.

In industrial processes, considerable energy savings are achieved by recovering the process condensate as well as the heat contained in the exhaust gases. Industrial condensate recovery results in savings of fuel, water and chemicals for the treatment of water [14].

Exhaust gases, together with cooling water, can be used for preheating raw materials in industrial processes in liquid or solid aggregate state. Examination of potential exhaust gas energy utilization in industry is geared towards energy conservation by using waste heat recovery to warm up the incoming cold streams (boiler feed water, combustion air, fuel, feedstock). It is possible to achieve energy savings using heat contained in the exhaust gases, which results in increased process economics and reduction of thermal pollution of the environment [14].

The thermal energy contained in the exhaust gas consists of latent and sensible heat. The latent heat of the steam is released into the environment, while the sensible heat contained in the condensate is unused [14]. In the case of an asphalt plant, the condensate is discharged into the environment through the chimney.

Exhaust gases in the asphalt plant are released into the atmosphere through the exhaust gas pipe. These gases are a mixture of burnt gas (or fuel oil) from the burner and dust particles. At the end of the slightly inclined rotary dryer, there is a burner, which has the function of burning gas coming into the burner and producing the open flame directed to the rotary drier. The amount of open flame can be controlled (increased or decreased) by an asphalt plant operator. In normal working conditions of about 70% of the asphalt plant capacity, the open flame is between 1/2 and 3/4 of the total length of the rotary drum. Fractions of stone material travel through the rotary drum for approximately one minute. The drum temperatures range from about 170 °C upwards, depending on the amount and moisture content of the aggregate and the type of bitumen mixture, as well as on additives in the bitumen mixture (e.g., recycled asphalt aggregate (RA)).

The rotary drum serves for drying and heating the aggregate fractions, i.e. it ensures that the fractions of the aggregate do not contain water when they leave the drum. There are two outputs in the rotary drum. One serves to extract particle fraction of stone material smaller than 0.71 mm (1 mm), while the other serves for the discharge of dried fractions greater than 0.71 mm (1 mm) to the hot fractions elevator, from where they continue to further production. Material particles smaller than 0.71 mm go to the dust suppression equipment through a so-called cyclone. At the entrance of the dust suppression system there are filters with which the particles collide and fall to the bottom (particle size of 0.50 mm and larger), from where they continue via the conveyor belt back to production. The other ones pass through these filters and travel to high temperature-resistant vibrating filter bags, where they are caught in the filter bags and shaken down to the bottom where there is a conveyor belt that sends them to an aggregate silo where excess aggregate is stored. Any particles that could not be caught by all the filters combined exit the drying drum through the exhaust gas pipe together with the gas. The concentration of particulates that are released through the exhaust gas pipe into the atmosphere is measured (according to HRN EN 13284-1:2017 *Stationary source emissions – Determination of low range mass concentration of dust – Part 1: Manual gravimetric method*.

3 EXPERIMENTAL RESEARCH

3.1 Research Methodology

Within the scope of exploring the possibilities of applying exhaust gases for drying and preheating stone material in the production of hot asphalt mixtures, tests of the loss of moisture content of different fractions of stone aggregates were performed in relation to the total moisture content of the fraction used as raw material in the production of asphalt mixtures.

Two types of asphalt plants are used for the production of hot asphalt mixes: plants for the production of asphalt mixtures of a cyclic type and a drum unit for continuous operation. On the asphalt plant of the cyclic type, the production starts on the pre-dispensers from which the aggregate fractions are dosed. The aggregate falls on a small infinite conveyor belt beneath the pre-despensers that has a regulated speed of rotation. The aggregate fraction mix travels on the infinite conveyor belt to the incline belt. Before the aggregate mixture falls on the incline belt there is a protective sieve on which the foreign bodies are removed together with the excess grain aggregates. With the incline belt, the aggregate mixture is transported to the rotary drum for drying. In the rotary drum, the aggregate fractions are heated to a temperature higher than 165 °C. The heated aggregate mixture from the rotary drum is transported by an elevator to the sieves and separated by fractions into special boxes. Each fraction, filler and bitumen are dosed by mass based on a predetermined mixture design. After dosing and mixing storage of the finished asphalt, mixture in silos is followed.

The idea is to add a conveyor belt dryer in the asphalt plant at the location where the incline conveyor belt is positioned, so that the conveyor belt dryer could use the thermal potential of the exhaust gases for drying the stone material (Fig. 1). The assumption is that the stone material will lose a certain percentage of moisture by passing through the conveyor belt drier over a certain time. By using waste gases emitted from the exhaust gas pipes into the atmosphere, their redirection and reuse can affect the cost of energy sources in the production of asphalt mixtures, and indirectly, reduce the amount of CO_2 emissions into the atmosphere.

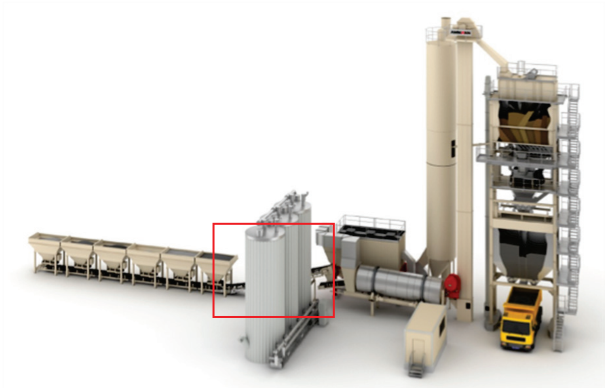

Figure 1 Positioning of conveyor belt dryer (image source of an asphalt plant https://www.ammann-group.com/en/news-media/news/modern-asphalt-production-uses-reclaimed-asphalt-2)

The moisture content of the aggregate is determined according to HRN EN 1097-5: 2008 *Tests for mechanical and physical properties of aggregates - Part 5: Determination of the water content by drying in a ventilated oven* by drying the stone material at a controlled temperature of 110 °C for 24 hours, with the possibility of drying to a "constant mass", which means no more than 0.1% change of mass over the period of one hour. This method of moisture determination according to the standard was used to determine the total moisture content of the fraction.

3.2 Laboratory Equipment and Resources

For the purposes of simulating the operation of the conveyor belt dryer, a laboratory model of a dryer (chamber) was designed. Testing of moisture content reduction was performed in the laboratory of Motičnjak (Varaždin), of the company COLAS Hrvatska d.d. For the test, the following test equipment was used:

- Conveyor belt dryer (plexiglass chamber with lid),
- a drying device that can control the temperature and air flow rate,
- stopwatch (possibility of operation from 0 to 86400 s),
- ventilating dryer (temperature range from 20° C to 200° C).

Samples of stone materials were taken at the unroofed stockpile of asphalt plant Motičnjak (COLAS Croatia d.d.). Samples of stone materials were fractional size 0/2, 2/4, 4/8 and 8/11. The origin of the fractions is from the quarries of Špica and Hruškovec (company Kaming d.d.). Recycled asphalt aggregate 0/11 RA was also sampled. The recycled asphalt aggregate was sampled at a roofed stockpile. All aggregates were sampled on the same day.

3.3 Preparation of Equipment and Samples

A drying device that enables the control of temperature and airflow rate was used to determine the characteristic measuring points. The device concept is such that it can control two basic temperatures and three basic airflow rates. All other combinations can be obtained with the above-mentioned conditions and the height of distribution of influential effects on the observed surface. Chapter 2 of this paper lists the parameters at the exhaust gas pipeline after the production process has been completed. That end of the process is actually the beginning of the input of temperature data. The exhaust gas flow rate in the exhaust gas pipe in this case is controlled. Exhaust gases will be supplied through the pipeline that starts at the exhaust gas pipeline or another suitable place and leads to the conveyor belt (chamber). At higher airflow rates and with particle sizes (fraction 0/2 or 0/4) that were tested, these particles (stone dust (rock flour) within the fractions 0/2 or 0/4) are lifted and therefore a loss occurs that is equivalent to their mass, which is unacceptable. When testing the reduced moisture content of the fraction, it is important to measure the weight loss in the process. Consequently, loss of particles in the process is not allowed. Laboratory model measurements determined the following ranges of input parameters of temperature and airflow rates (Tab. 1).

Table 1 Input parameters of laboratory chamber

Velocity, v (m/s)	Temperature, T (°C)	Time, t (s)
3.86	33.1	30
	50.4	45
	71.7	60
4.53	39.2	30
	60.9	45
	85.3	60
5.94	37.8	30
	64.3	45
	94.0	60

Samples of fractions of stone material sampled at the asphalt plant stockpile were delivered to the laboratory with natural moisture content present at the moment of sampling.

3.3.1 Sampling

Individual samples of stone material, in approximately the same amount, were taken from different places at different depths, dispersed across the entire stockpile. When choosing the site and the number of individual samples, account should be taken of the form of the stockpile, its shape and the possibility of segregation within the stockpile. An individual sample is taken using a blade or shovel at the lowest point of a single hole. The aggregate in the stockpile has a tendency to segregate, so it is best, if possible, to sample it from the inside of the stockpile, i.e. not to take individual samples close to the surface. This particularly applies to coarse aggregates. In order to obtain the sampling surface from the inside of the stockpile, a loader is used. A certain number of interventions of the loader prepares the stockpile for sampling, at which point individual samples are taken by shovels from randomly selected sites across the whole new stockpile (HRN EN 932-1: 2003 *Tests for general properties of aggregates - Part 1: Methods for sampling*).

When reducing samples by using the quartering method, a laboratory sample is placed on the desktop. The sample is thoroughly mixed and the first cone is made, after which the second cone is made from the first one. This procedure is repeated three times. When making the cones, the contents of the shovel are placed on the top of the cone so that the aggregate is scattered across all sides of the cone, allowing it to become uniformly distributed so that various grain sizes mix well with one another. The third cone is flattened by repeated inserting of the shovel vertically through the top of the cone so that a flat pile of uniform diameter and thickness is made. Thus flattened pile is then quartered by drawing two vertical lines across it. Two of the opposing quarters are removed and the shovel is used to form a pile of the remaining two quarters (HRN EN 932-2: 2003 *Tests for general properties of aggregates - Part 2: Methods for reducing laboratory samples*).

The mixing and quartering process is repeated until the required sample size is obtained (Fig. 2).

Figure 2 Homogenized and prepared test sample

3.3.2 Testing

After the preparation and homogenization of the test samples, the test is carried out. The test procedure is carried out as follows:

1) Stone material (fraction 0/2) with natural moisture content is weighed and the mass of the sample is determined.
2) After weighing the sample is placed in the chamber.
3) The drying unit is set to a certain airflow rate and temperature and needs to be switched on. The exposure of the sample to temperature and airflow at the set rate lasts 30 seconds.
4) After the required time, the device is switched off, the sample is placed on the scale, its weight is read and the result is recorded.
5) The following sample of the same fraction is taken and its mass is determined prior to drying. It is tested under the same conditions of airflow rate and temperature, but the drying time is 45 seconds, after which the mass of the sample is determined again.
6) Then, the next sample of the same fraction is taken and tested under the same conditions of airflow rate and temperature, but the drying time is 60 seconds, after which the mass of the sample is determined again.

The width of the incline conveyor belt is 0.7 m, while the maximum depth is 0.08 m (Fig. 3). During the operation of the asphalt plant at maximum capacity, conveyor belt load is ca. 0.5 m wide and 0.06 m thick.

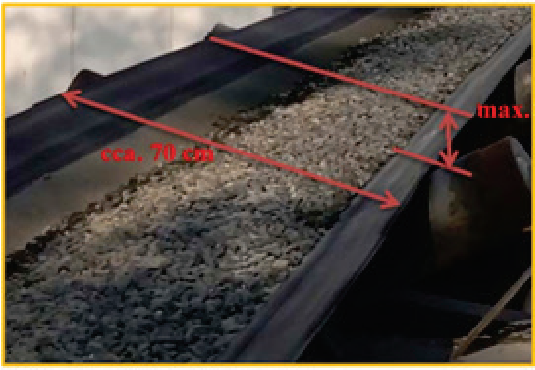

Figure 3 Dimensions and appearance of the incline conveyor belt

For the sample size calculation, one takes into account average values of the width of the conveyor belt of 0.5 m and the average thickness of the layer of stone material fractions of 0.03 m. The surface area of the stone material placed along 1 meter of conveyor belt is 0.5 m^2. The bulk density of the stone material fraction 0/4 mm is approximately 1.7 t/m^3. The result of 25.5 kg of fraction 0/4 is obtained. The bulk density of the 4/8 mm stone material fraction is approximately 1.4 t/m^3, which gives a mass of 21.0 kg. The mass of fraction 8/11 can be calculated the same way. Based on the defined bitumen mixture recipe, which for the wearing course AC 11 surf means a ratio of 40% of fraction 0/4 and 30% of 4/8 and 8/11 each, 1 m^2 accounts for approx. 45.6 kg of stone fractions.

The laboratory sample in the vessel is 0.1 × 0.1 × 0.03 m in size. It can be concluded that a laboratory sample measures 0.003 m^3 or 510 g. As a result, it is necessary to find correlations between reduced moisture content in the samples after the test. One needs to identify the dependence of the reduced moisture content function on time, temperature and velocity of air flow $w_{d/D} = f(t, T, v)$. One observes how the reduced moisture content affects the observed thickness of the layer.

The test results are as follows. Tab. 2 shows the test results for fraction 0/2. Declared density of fraction 0/2 Špica (determined according to HRN EN 1097-6: 2013 *Tests for mechanical and physical properties of aggregates - Part 6: Determination of particle density and water absorption*) is 2.73 Mg/m^3 and water absorption (determined according to the same standard) is 0.8%.

The test results from Tab. 2 are presented in Fig. 4. Fig. 4 shows the results of moisture reduction measurement over time. By increasing the drying time, a growing trend of moisture content reduction at the same temperature is visible. In addition, there is a visible trend of reducing the moisture content by increasing the drying temperature.

Table 2 Test results for fraction 0/2

Fraction 0/2, Špica, natural moisture content 3.07%			
Airflow rate (m/s)	Temperature (°C)	Time (s)	Result of reduced moisture content (%)
3.86	33.1	30	0.12
3.86	33.1	45	0.16
3.86	33.1	60	0.22
3.86	50.4	30	0.16
3.86	50.4	45	0.21
3.86	50.4	60	0.26
3.86	71.7	30	0.22
3.86	71.7	45	0.28
3.86	71.7	60	0.33
4.53	39.2	30	0.14
4.53	39.2	45	0.18
4.53	39.2	60	0.24
4.53	60.9	30	0.16
4.53	60.9	45	0.24
4.53	60.9	60	0.35
4.53	85.3	30	0.22
4.53	85.3	45	0.29
4.53	85.3	60	0.35
5.94	37.8	30	0.22
5.94	37.8	45	0.29
5.94	37.8	60	0.35
5.94	64.3	30	0.28
5.94	64.3	45	0.37
5.94	64.3	60	0.49
5.94	94.0	30	0.37
5.94	94.0	45	0.47
5.94	94.0	60	0.61

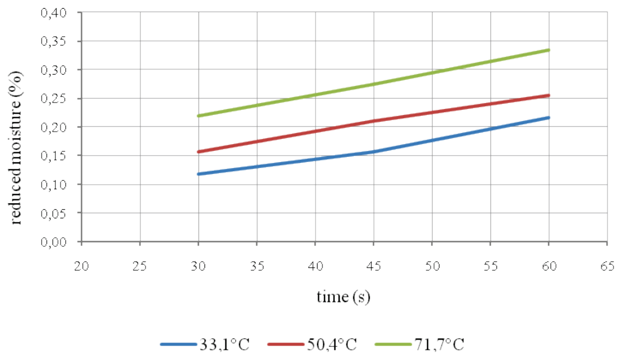

Figure 4 Time - moisture content diagram of fraction 0/2 with corresponding temperatures at velocity of 3.86 m/s

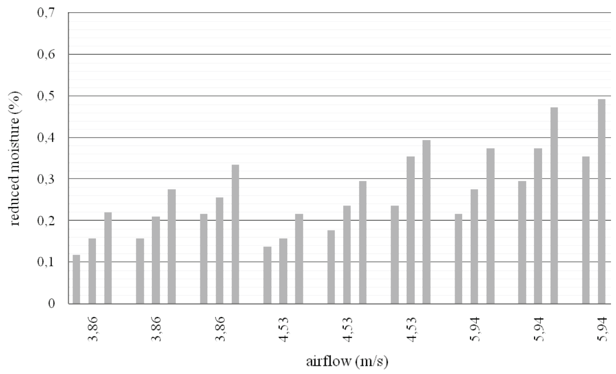

Figure 5 Moisture content - temperature diagram for fraction 0/2 with the corresponding drying time of 30 s, 45 s and 60 s

Fig. 5 shows the results of moisture reduction measurement relative to the airflow rate in the drying chamber. At different airflow rates in the chamber under the same drying times and temperatures, a trend of increased moisture content reduction is visible.

4 RESULTS ANALYSIS

This item provides an analysis of the obtained results and the calculation of equations for reduced moisture content of fractions of stone materials, as well as the obtaining of the function $w_{d/D} = f(t, T, v)$. The calculation of reduced moisture content was performed according to the basic equation:

$$w_{d/D} = \frac{m - m_{SM}}{m} \cdot 100 \ (\%) \tag{1}$$

where: $w_{d/D}$ is reduced moisture content of tested fraction (%), m is the mass of wet material (kg), m_{SM} is the mass of dry material (kg).

In the example for fraction 0/2, with the following parameters:
- mass of wet sample, m = 400.00 g
- velocity, v = 3.86 m/s
- temperature, T = 33.1 °C
- time, t = 60 s
- sample mass after treatment is m_{SM} = 398.70 g.

By entering the parameters in Eq. (1), one gets:

$$w_{d/D} = \frac{400.00 - 398.70}{400.00} \cdot 100 = 0.33\%$$

4.1 Calculation of Reduced Moisture Content for Fraction 0/2

Tab. 3 shows the results of testing with regard to the correlation of drying time and moisture content for the fraction of stone material 0/2 (input moisture content 3.07%) at the conveyor belt speed of 3.86 m/s and corresponding temperatures. Analysis of test results provided the linear equation (Fig. 6). The temperature coefficients in Tab. 3 were defined based on the best overlapping of the curve with the result of minimum error.

Table 3 Relationship between the observed results pertaining to time - moisture content for fraction 0/2

Temperature coefficient, α		**1**	**1.27**	**1.7**
Temperature	°C	33.1	50.4	71.7
Time	30 s	0.12	0.16	0.22
Time	45 s	0.16	0.21	0.28
Time	60 s	0.22	0.26	0.33

Diagram that describes the relationship between temperature and reduced moisture (experimental values) for 30 s was constructed. Then, curves for the other two periods (45 s and 60 s) were added on the same diagram. For the first curve (30 s curve), an equation with a minimum regression error against the experimentally obtained results was made, and the coefficient 1 is noted for all three periods. Due to the similarity of the curve behavior, the next coefficient 1.27 determined for the best matching equation with a minimum regression error against the experimentally obtained measurement results. In the same way, the third coefficient of 1.6 was determined.

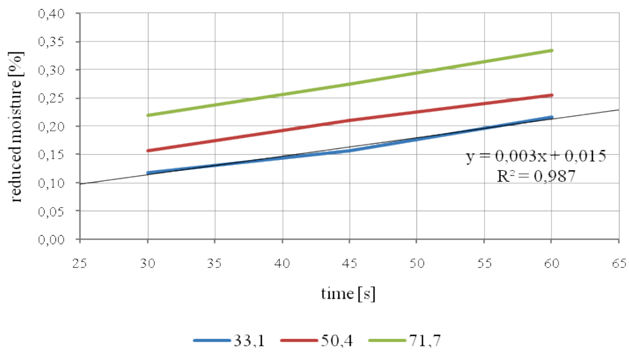

Figure 6 Time - moisture content diagram of the fraction 0/2 with regression

The equation shown is used to find the temperature coefficient.

$$w_{0/2} = \alpha \cdot (0.0033 \cdot t + 0.0155) \ (\%) \tag{2}$$

where: $w_{0/2}$ is reduced moisture content for fraction 0/2, %; α is the required temperature coefficient; t is time, s.

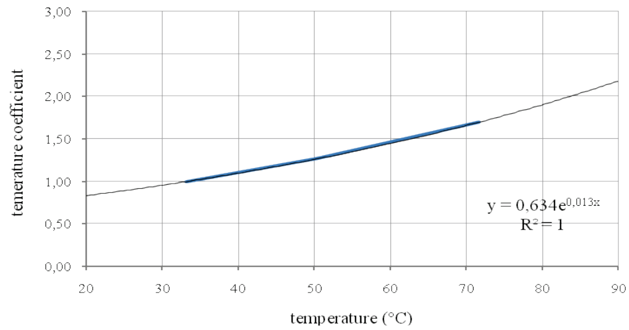

Figure 7 Temperature coefficient diagram for fraction 0/2 with regression

From Tab. 3 of temperature coefficients, a regression function was obtained which best suits the correlation of coefficients and temperature (Fig. 7). All the required coefficients were chosen based on minimum error when defining the behaviour equation.

$$\text{Temperature coefficient, } \alpha = 0.6348 \cdot e^{0.0137x} \tag{3}$$

where: α is the required temperature coefficient; e is the natural logarithm, amounting to ~ 2.71828; T is temperature, °C.

At this point the moisture content reduction equation is extended by a coefficient β, and so we have:

$$w_{0/2} = \alpha \cdot \beta \cdot (0.0033 \cdot t + 0.0155) \ (\%) \tag{4}$$

where β is the velocity coefficient.

Eq. (4) requires the coefficients of velocity that best coincide with the measured values of the achieved reduced moisture content (Tab. 4 and Fig. 8).

Table 4 Velocity coefficients for fraction 0/2

Velocity coefficient, β		**1.01**	**1.05**	**1.5**
Velocity	m/s	3.86	4.53	5.94

$$\text{Velocity coefficient } \beta = 0.2485 \cdot v - 0.0002 \tag{5}$$

At this point, the equation for fraction 0/2 mm is:

$$w_{0/2} = \left(\alpha = 0.6348 \cdot e^{0.0137x}\right) \cdot (0.2485 \cdot v - 0.0002) \cdot (0.0033 \cdot t + 0.0155) \ (\%) \tag{6}$$

where v is the airflow rate, m/s.

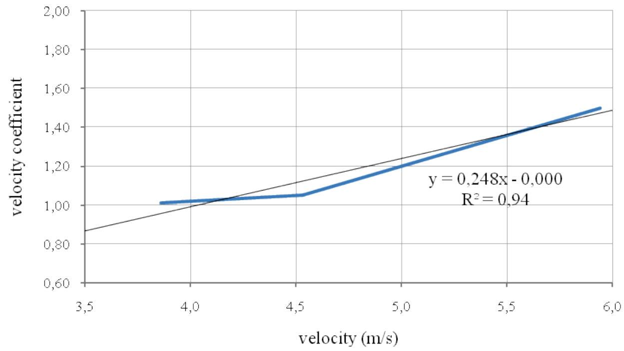

Figure 8 Velocity coefficient diagram for fraction 0/2 with regression

After the formed and presented equations, deviations of the mathematical and experimental models were calculated. The results are shown in Tab. 5.

Table 5 Results of experimental testing and mathematical model of fraction 0/2, Špica

Fraction 0/2 Špica, natural moisture content 3.07%				
Airflow rate (m/s)	Temperature (°C)	Time (s)	Experimental result of reduced moisture content (%)	Mathematical result of reduced moisture content (%)
3.86	33.1	30	0.12	0.11
3.86	33.1	45	0.16	0.16
3.86	33.1	60	0.22	0.20
3.86	50.4	30	0.16	0.14
3.86	50.4	45	0.21	0.20
3.86	50.4	60	0.26	0.26
3.86	71.7	30	0.22	0.19
3.86	71.7	45	0.28	0.27
3.86	71.7	60	0.33	0.35
4.53	39.2	30	0.14	0.14
4.53	39.2	45	0.18	0.20
4.53	39.2	60	0.24	0.26
4.53	60.9	30	0.16	0.19
4.53	60.9	45	0.24	0.27
4.53	60.9	60	0.35	0.35
4.53	85.3	30	0.22	0.26
4.53	85.3	45	0.29	0.38
4.53	85.3	60	0.35	0.49
5.94	37.8	30	0.22	0.18
5.94	37.8	45	0.29	0.26
5.94	37.8	60	0.35	0.34
5.94	64.3	30	0.28	0.26
5.94	64.3	45	0.37	0.37
5.94	64.3	60	0.49	0.48
5.94	94.0	30	0.37	0.39
5.94	94.0	45	0.47	0.56
5.94	94.0	60	0.61	0.72

5 CONCLUSION

The research results show the possibilities of exploiting the exhaust gas heat energy and contribute to the improvement and reduction of energy costs in the process of producing hot asphalt mixtures while simultaneously addressing one of the biggest problems in the work of asphalt plants - air pollution.

Asphalt mixture production is a fast and continuous process. Dosing the aggregate components and mixing them with the binder is expressed in seconds. From the results presented, it can be concluded that by exposing the stone material to short-term drying, a part of the moisture content is lost. Three important parameters describe the relationship between reducing moisture content of mineral mixtures by using the heat of exhaust gas in a short-term drying process: (1) exposure time, (2) temperature and (3) the rate of airflow.

(1) By exposing the stone material to short-term drying for a period of 30 to 60 seconds, at temperatures between 30 °C and 100 °C, the aggregate will lose a part of the moisture content - for fraction 0/2, moisture content loss ranges from 0.11 to 0.72%. By prolonging the drying time, the loss of moisture content would increase accordingly. Such prolongation of time pertains to a conveyor belt dryer, which would have several levels, allowing for longer exposure time of the aggregate.

(2) Temperature is the second key factor. It is apparent from the test that with the increase in temperature, the percentage of moisture content of the aggregate is reduced. In the current practice of production of bitumen mixtures, production temperatures range from a minimum of 110 °C. This is caused by the fact that the drying of aggregate must occur at higher temperatures due to the need to evaporate the water from the aggregate. At all lower temperatures it is more difficult to evaporate all the water from the stone, and at the same time, the drying time is increased. When temperature-reducing technologies are used in the production of bitumen mixtures, the type of binder used is always known (in other words, one knows the optimum bonding temperature (for bitumen)). When a sufficient drying temperature is not achieved in the rotary dryer, the aggregate begins to cling on the walls of the drum. It can be concluded that temperature is critical for this technological process. Thus, the mode of utilization of that temperature that is produced at the rotary drum and continues further into the production system, and its harvesting, whether at the place immediately behind the filter bag or at another suitable place, is especially emphasized. The aggregate that comes out of the conveyor belt dryer, besides having a reduced moisture content, also has a certain temperature that it takes on during the drying phase. It is well known that the temperature of the input aggregate in the production process is one of the factors that affect the reduction of energy in overall production.

(3) The rate of airflow of a certain temperature as a third factor is the consequence of the kinetic process of bringing in the temperature. Here one can see a tendency in relation to the empty spaces between the aggregate grains (when the empty spaces are larger, warm air can reach all parts of the aggregate grain, which is not the case when the empty spaces between the aggregate grains are smaller). One needs to emphasize, however, that in case of too high speed, small aggregates are uplifted, which is an undesirable effect. Therefore, it is necessary to control the airflow. Fractions of aggregate with grains smaller than 4 mm have high moisture content due to the surface area of the grains in relation to unit volume, unlike larger grain aggregates, for example, those found in any large fraction.

New knowledge and research results represent a significant, multifaceted contribution in terms of energy, ecology and economics. The energy-related contribution would be reflected in the increase of energy efficiency through the reuse of the energy potential of asphalt plant exhaust gases in the drying process of aggregates, which is recognized as one of the fundamental determinants of the Energy Strategy of the Republic of Croatia by 2020. Ecological contribution would be the simultaneous reducing of the adverse impact of exhaust gases from asphalt plants on the environment, especially those pertaining to air quality. The economic contribution would be felt in the reduction of the cost of fuel (petroleum, gas, oil) required for heating the aggregate. All planned effects (contributions) are fully in line with the guidelines that prescribe the concept of sustainable development and reflect the potential and usability of the described model of management of thermal energy of exhaust gases in asphalt plants.

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