Reducing energy consumption is one of the priorities of big enterprises, especially the asphalt concrete production companies. Solving this problem requires the step by step analysis of the whole production technology. The production of asphalt concrete mixtures consists of four main stages, in which the final one is carried out in a mixer of an asphalt concrete plant, where all the ingredients are mixed and turn into a finished product. Figure 1 is a schematic diagram of an asphalt concrete mixing plant with all the flows of ingredients joining into this process. From this, we can express the balance of energy and exergy occurring here.

The energy balance of the mixer, calculated on basic per ton of the asphalt concrete mixture, has the form:

\[ g_{\text{sat}} h'_{\text{sat}} + g_{\text{as}} h'_{\text{as}} + g_{\text{a}} h'_{\text{a}} + g_{\text{nt}} k_{\text{nt}} h'_{\text{nt}} + w'_{\text{a}} = q'_{\text{oc}} + g_{\text{sat}} k_{\text{nt}} h'_{\text{nt}} + h''_{\text{a}} + \text{MJ/t}, \]  

(1)
Where:

- $h'_{mp}$: MJ/t: the partial mass enthalpy of the input flow of the mineral powder;
- $g_{sm}$, $g_{sv}$, $g_{o}$: components calculated by the weight ratio of the asphalt concrete mixtures: the mineral powder, the mineral filler and the bitumen. The formula, converting from components calculated by the weight ratio of mineral materials into components determined by the total weight is:

$$
\sum g_{j}^{MM} = \frac{g_{j}^{MM}}{1 + \sum g_{j}^{MM}}
$$

- $h'_{as}$, $h'_{ab}$: MJ/t: the partial mass enthalpy of the input and output air flows with the moisture content $d_w$, kg/kg, bringing the mineral powder into the mixer through the pneumatic transporter;
- $h'_{o}$: MJ/t: the partial mass enthalpy of the bitumen;
- $w'_{el}$: MJ/t: the partial electrical power per ton of the asphalt concrete mixture, which is required for the work of the mixer. It is determined by:

$$
w'_{el} = W_{el}/G'_{abs}, \text{MJ/t}
$$

- $W_{el}$: MJ: The electrical power, which is supplied to the mixer during the time of the mixing process.
- $G'_{abs}$: t: The weight of the finished asphalt concrete mixture, which is received during the time of the mixing process.
- $h''_{as}$: MJ/t: the partial mass enthalpy of the output flow of the asphalt concrete mixture, determined by:

$$
h''_{as} = \sum g_{j} \cdot \frac{c}{p_{o}} \cdot t''_{as}, \text{MJ/t},
$$

Where:

- $g_{j}$: components, calculated by weight ratio of the asphalt concrete mixture.
- $\frac{c}{p_{o}} \cdot t''_{as}$: kJ/(kg.K): The average weight heat capacity at constant pressure of components of the asphalt concrete mixture, in the temperature interval $0 \div t''_{as}$. 

- $g_{as}$, $g_{sv}$, $g_{o}$: components calculated by the weight ratio of the asphalt concrete mixtures: the mineral powder, the mineral filler and the bitumen.
- \( t'' \text{°C} \): temperature of the finished asphalt concrete mixture.
- \( k_{\text{int}} \): the partial flow of air per ton of the transported mineral powder.
- \( q''_{\text{oc}} \): MJ/t: loss of heat through the fencing structure. There are many methods to determine the quantity of heat lost through fencing structure, such as computing by scatter coefficient \( \eta_{\text{pmtp}} \) in useful flow of heat \( q_{\text{cm}} \) of the mixing process.

\[
q''_{\text{oc}} = (1 - \eta_{\text{pmtp}}) \cdot q_{\text{cm}}
\] (5)

Raising temperature of the mixture to the required value point is done directly thanks to the power of mineral fillers in the process of mixing and receiving the asphalt concrete mixture. The heat \( q_{\text{cm}} \) of process mixture can be determined by the heat of the cooling mineral fillers process.

\[
q_{\text{cm}} = g_{\text{mr}}(h'_{\text{mr}} - h''_{\text{mr}}), \text{MJ/t},
\] (6)

The energy balance of the mixer is shown in fig 2.

![Fig 2. The energy balance of the mixer of an asphalt concrete plant](image)

The exergy balance per ton the asphalt concrete mixture of the mixer can be written in this form:

\[
g_{\text{mr}}'e_{\text{mr}}' + g_{\text{mr}}'e_{\text{mr}} + g_{\text{mr}}'e_{\text{mr}} + g_{\text{mr}}'k_{\text{mr}}e_{\text{mr}} + w'_{\text{mr}} = d_c + d_l + e''_{\text{moc}}, \text{MJ/t}
\] (7)

Where:
- \( e_{\text{mr}}', e_{\text{mr}}', e_{\text{mr}}', \text{kJ/t} \) – the partial mass exergy of the mineral powder, the mineral filler and the bitumen flows; the other components of the inputs are described above.
Outputs of the exergy balance (7) include:

- \( d_i \), MJ/t, internal exergy loss of structure, determined by the balanced method [1].

- \( d_e \), MJ/t, – external exergy loss of structure, determined by:

\[
d_e = e''_{q,oc} + g_{am} \cdot k_{ap} \cdot e''_a, \text{ MJ/t}, \tag{8}
\]

Where:

- \( e''_a \), MJ/t - the partial mass exergy of the output flow of air for the pneumatic transporter, bringing the mineral powder to the mixer.

- \( e''_{q,oc} \), MJ/t - the partial exergy of the heat flow, that scatters through the fencing structure, computed on basic per ton of the asphalt concrete mixture, determined by relations in the work [1]. In the calculation of the value \( e''_{q,oc} \), the mean temperature is taken as the temperature of the asphalt concrete mixture. Otherwise, in order to assess the influence of that heat flow energy, scattering through the fencing structure, on the outside environment, the mean temperature is taken as the temperature of the outer surface of the mixer.

- \( e''_{a,as} \), MJ/t - the partial mass exergy of the finished asphalt concrete mixture, which contains exergy of all components in material flows. In general, the asphalt concrete mixture concludes the mineral powder, the mineral filler and the bitumen flows.

- Chemical components of the mineral filler exergy \( e_{\mu,M3} = 0 \), because chemical components of exergy of \( \text{SiO}_2 \), the main component of mineral fillers, is zero due to the work [2].

- From that work, we also find chemical components of exergy of the mineral powder \( e_{\mu,am} = 1045 \) MJ/t, because the dolomite \( \text{CaCO}_3 \) is often the main component of the mineral powder. Chemical components of exergy of the bitumen can not be calculated in the same way as the other above chemical compounds. The most difficulty is the unknown molecular structure of the bitumen. Moreover, in SNG the bitumen is not a qualified product as light oil, but the last product with undetermined qualify. In that case, the method in work [1] should be used to calculate chemical components of exergy of oil:

\[
e_{\mu} = \kappa \cdot (1066 + 67.4 \omega + 1875 \nu + 3784 \sigma + 177.8 \xi), \text{ kJ/kg},
\]

where:

\[
\kappa = 7.817 \cdot C;
\omega = 6 \cdot H / C;
\nu = (3/7) \cdot (N/C);
\sigma = 1 + 3 \cdot (H - (O - S) / 8) / C;
\xi = (3/8) \cdot S / C;
C + H + O + N = 1: \text{Mass fractions.}
\]
According to work [3], the compositions of the bitumen are averaged: C: from 70 to 85%, H: from 8 to 12%, O: from 0.2 to 5%; S: from 0.5 to 7%; N: from 0.2 to 1%. The calculation with above values gives us the chemical components of exergy of the bitumen $e_\mu = 38\div44$ MJ/kg. With errors of the above calculation chain, we define the value $e_\mu = 41$ MJ/kg that consists with $e_\mu$ of the other oil products such as: crude oil - $e_\mu = 46$ MJ/kg, diesel oil - $e_\mu = 42$ MJ/kg due to the work [4]. The change of $e_\mu$ to the heavier fractions of oil products shows us that the above result is reasonable and acceptable.

$e''_{c,abc}$, MJ/t: components of exergy of the asphalt concrete mixture, which is called concentrative components. Its value, determined by the adhesion of the bitumen and the mineral components, shows the quality of the finished asphalt concrete mixture. As the result, it is necessary to research more deeply about the exergy transformation in the mixer.

The exergy transformation is shown in fig 3 by bar chart Grassman.

Fig 3. The exergy transformation of asphalt concrete mixture-creating process

Obviously, the exergy transit flows are the flows of components: $E''_{\tau,abc}$, $E''_{r,6}$, $E''_{\tau,mp}$, $E''_{r,6}$. Useful components are the thermal component of exergy of the mineral powder - $E''_{\tau,mp}$ and component of exergy of the asphalt concrete mixture - $E''_{c,abc}$, which are still undefined clearly.
The clear define allows us to assess energy influence on ingredients of the asphalt concrete mixture in the mixer.

The adhesion requires the contact of the bitumen and all particles of the mineral fillers and the mineral powder. The happening of the contact requires expending of energy, in which its minimum value is $E''_{\text{k,абс}}$. This can be followed the chart analysis (fig 4): The mechanical mixing work $L'$ cannot be less than $E''_{\text{k,абс}}$ to ensure the necessary condition for the happening of the exergy balance [1].

$$\Sigma E' > \Sigma E''$$

In the ideal condition, the energy expending into the ingredient mixture is defined by the energy of the adhesive interaction.

In conclusion, the component of exergy of the asphalt concrete mixture $E''_{\text{k,абс}}$ determines the necessary minimum amount of energy for an ideal mixer; In fact, the energy expending in a real mixer must be equal or more than $E''_{\text{k,абс}}$. Besides, calculating concentrative components of exergy of the asphalt concrete mixture $E''_{\text{k,абс}}$ has an important technological role, as in the case of cement [5, 6], because this will be the base to assess the quality of the asphalt concrete mixture, which is very important in practice.

Reference


