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Development and justification of the treatment system layout scheme for dust emissions from mobile and portable asphalt-concrete plants

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Abstract: Nowadays, reducing the amount of dust in urban atmosphere is an urgent task for the majority of industrially advanced countries in the world. Road construction works are one of the factors influencing the increase in the dust particles concentration in the atmospheric air. The authors present the treatment schemes for dust emissions from mobile and portable asphalt concrete plants applying dust collectors with countercurrent swirling flows. They conducted an analytical investigation of the operation of the designed layout schemes applying dust collectors with countercurrent swirling flows (CSF), dust concentrators and bag filters. The justification of the optimum layout scheme was presented.

The dust level in the territories of populated areas is formed due to various factors [1-4]. One of them is the road construction works the performance of which without ecologically proved measures results in the exceedance of the maximum permissible concentrations of dust particles in the air of populated areas.

Dust particles contained in the emissions from asphalt mixing units of asphalt concrete plants are characterized by highly dispersed structure ($d_{50} = 36...78 \mu\text{m}$) as well as by high values of hovering velocities ($V_{\text{hov}} = 5,8...7,3 \text{ m/s}$). The given data describing the ratio of aerodynamic and mass characteristics as well as comparably low adhesive capacity preventing the process of coarsening of the collected particles due to adhesion and coagulant formation allow concluding on the fact that under the given conditions the use of classical inertial dust collectors does not ensure the required values of the degree of dust emissions treatment.

A comparably low adhesion capacity of dust particles in the combination with the highly dispersed structure are the factors favoring the application of filtration treatment methods, in particular of fabric bag filters. However, the application of filtration methods is limited to the cases of high concentrations of dust particles ($C = 1980...2160 \text{ mg/m}^3$). Relatively high concentrations make the use of filters economically unsound owing to enhanced filter clogging and filtering fabric wear as well as to the necessity of frequent shaking. In addition, due to strict mass-dimension restrictions determined by the requirements to the equipment of mobile and portable units, the use of bag filters is rather difficult. Besides that, because of high values of aerodynamic drag, the use of the filters as of the main dust



collecting equipment in the systems of emissions treatment of mobile and portable asphalt-mixing units is complicated by the necessity to use energy-consuming draft systems.

The two-stage layout with inertial dust collector at the first stage reduces the loads on the filtering elements and solves the problem of fine dust particles collection. However, the mass-dimensional characteristics of the two-stage systems provide serious difficulties for the transportation and mounting of their elements, and the problem of high energy consumption remains unsolved. The abovementioned facts dictate comparably high capital, maintenance and depreciation expenses which, being combined with operation complexity, make the use of the two-stage systems unreasonable.

According to the combination of mass-dimensional characteristics, the degree of treatment, simplicity, reliability and economic efficiency, dust collectors with countercurrent swirling flows (CSF) most accurately meet the specified requirements. They exhibit the main advantages of inertial dust collectors of cyclone type such as the simplicity of design and operation, reliability and low cost and are characterized by significantly larger values of total and fractional collection efficiency [5-7].

It should be mentioned that the comparably higher efficiency of fine particles separation does not allow for the required treatment degree in all the cases since CSF dust collectors are based on the principles of inertial separation, although they have a more efficient design. Due to the fact that portable and especially mobile asphalt concrete plants may operate in the immediate proximity to residential development, the treatment systems for the emissions from asphalt mixing units being a part of those plants should meet stricter requirements concerning the quality of dust emissions treatment with the special attention paid to the collection of fine dust fractions.

One of the possible solutions aimed at enhancing the fractional efficiency of CSF dust collectors is the arrangement of the delivery of flows with different concentration of dust to primary and secondary inlets [7 -10].

The use of a bag filter is suggested for the treatment of the flow delivered to the secondary inlet of CSF dust collector. Taking into account that only a part of the total dust-gas mixture rate delivered for treatment comes to the secondary inlet, a possibility appears to use a filter with lower performance capacity than in the case with a two-stage layout, which allows reducing the aerodynamic drag as well as the mass, dimensions and, hence, the cost of dust treatment equipment.

In order to enhance the fractional efficiency of the unit and to reduce the load on the filtering element, for the purpose of increasing the service life at lower maintenance expenses, it is desirable to arrange the dust-gas flows in the way that fine particles in low concentration are delivered to filtration while large particles in high concentration come to the primary inlet of CSF dust collector. To ensure the given distribution of flows, a centrifugal dust concentrator is suggested to be introduced into the layout scheme. The primary flow leaving the centrifugal dust concentrator contains the particles of the largest fractions which are separated under the action of the centrifugal force, while particles of smaller fractions avoid the inertial separation and get to the secondary flow delivered to filtration.

Figure 1 presents the two suggested layout schemes of the systems of dust emissions treatment for mobile and portable asphalt mixing units applying CSF dust collectors with the splitting into primary and secondary flows by means of centrifugal dust concentrators and the treatment of the secondary flow in bag filters to follow.

The scheme given in figure 1a) works in the following way: the dusted gases exhausted from the rotary dryer of the asphalt mixing unit (1) come to the tangential inlet of the scroll swirler (2) of the centrifugal dust concentrator (3) in which the process of centrifugal separation of solid dust particles takes place. Due to the prevalence of the inertial forces over the aerodynamic ones, particles of large fractions leave the separation chamber of the centrifugal dust concentrator (3) through the tangential branch duct and are delivered to the primary inlet (5) of the CSF dust collector (4). The flow containing dust particles of smaller fractions, which have avoided the separation, continues its motion in the axial direction along the separation chamber of the centrifugal dust concentrator (3) and upon going through the chamber it is delivered to the inlet branch duct of the bag filter (8). After the filtration procedure, the clean flow from the filter (8) is routed to the branch duct of the secondary inlet (6) of the CSF dust

collector (4). And after the treatment in the collector, the flow is headed to the outlet to the smoke pipe (conventionally, not shown) under the action of the air depression produced by the ventilating fan (9).

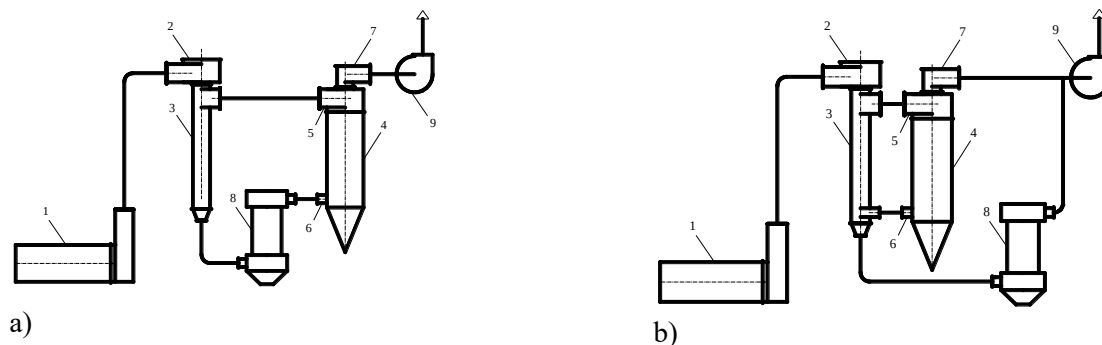


Figure 1. The layout schemes of the system of dust emission treatment: 1 – rotary dryer of asphalt mixing unit; 2 – scroll swirler of the centrifugal dust concentrator; 3 – cylindrical separation chamber of the centrifugal dust concentrator; 4 – CSF dust collector; 5 – primary inlet of the dust collector; 6 – secondary inlet of the dust collector; 7 – unswirler of the flow; 8 – bag filter; 9 – draft system.

Taking into account the complicated layout of the system as well as the presence of a large number of swirling elements, aerodynamic drag reduction is a vital task since its enhanced values cause a decrease in the energy efficiency and hence the growth of maintenance expenditures. In order to recover the residual energy produced by the swirling of the flow that underwent treatment in the separation chamber of CSF dust collector, a tangential flow unswirler is installed at the outlet from the collector instead of a regular ventilation brunch duct. The use of the unswirler allows reducing the aerodynamic loss due to the application of the kinetic energy of flow rotation. The brunch ducts connecting the separation chamber of the centrifugal dust concentrator with the primary and the secondary (scheme “b”) brunch ducts of the CSF dust collector are designed as tangential ones, which allows for the recovery of flow swirling energy in the dust concentrator.

The operating principle of the layout scheme presented in figure 1b) lies in the combination of two parallel brunches into which the low concentrated flow is split after the treatment in the centrifugal dust concentrator (3). A part of the low concentrated flow is delivered to the secondary brunch duct (6) of the CSF dust collector (4) along the tangential brunch duct in order to reduce the aerodynamic drag, while the other part is headed to the bag filter (8) for treatment and after this procedure it is delivered to the outlet.

The use of the layout scheme “b” allows for smaller dimensions and mass of the bag filter through the reduction of the gas rate delivered for treatment, in addition the aerodynamic drag of the system is lower. On the other hand, the system designed according to the scheme “a” will obviously show higher total efficiency of treatment owing to the fact that less fine particles are delivered to the secondary inlet of the CSF dust collector since they are caught by the filtering element of the bag filter (8). In this, case the fractional efficiency of the CSF dust collector which exerts the highest influence on the value of the total efficiency of treatment since the largest part of the dust-gas rate is delivered for treatment right there increases due to the absence of fine particle penetration from the secondary swirling flow to the outlet brunch duct.

The variation of the total efficiency value will depend on a number of factors. The ratio of dust particles concentrations after the flow splitting in the centrifugal dust concentrator, the ratio of the gas rates delivered for treatment along various sections of the system, the values of the treatment efficiency in the bag filter and the CSF dust collector etc. are among them.

For the purpose of the conducted comparative analysis, the following quantities were adopted as the input data: η_{CSF} – the collection efficiency by the CSF dust collector which is the function of the proportion of the gas rate delivered to the secondary inlet and the ratio of the dust particles concentrations in the flows delivered to the primary and secondary inlets $\eta_{CSF} = f(L_2 \times L_{total}^{-1}, C_2 \times C_1^{-1})$; η_f – the efficiency of the SMC bag filter adopted according to the catalogued data and based on the concentrations and size distribution of dust particles contained in the gases delivered for treatment; η_{con} – the efficiency of flow splitting by the centrifugal dust concentrator characterized by the ratio of the concentrations in the primary and secondary flows $\eta_{con} = 1 - C_2 \times C_1^{-1}$.

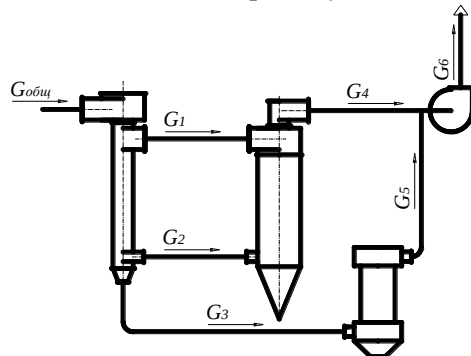


Figure 2. The model of the system of dust emissions treatment designed according to the scheme with a bag filter installed in parallel.

Figure 2 presents the model of the system of dust emissions treatment designed according to the scheme with a bag filter installed in parallel (the second variant of the layout). The value of the quantity of the total efficiency of treatment through the use of the suggested layout scheme is determined on the basis of the solution of the system of balance equations formulated according to the model presented in figure 2, which characterize the dust particles mass:

$$G_{total} = G_1 + G_2 + G_3 \quad G_{total} = \eta_{con} G_1 K G_{total} = G_3 G_4 = (G_1 + G_2)(1 - \eta_{CSF}) G_6 = G_4 + G_5 \quad (1)$$

$$G_5 = G_3(1 - \eta_f)$$

where: G_{total} – is the dust mass flow rate delivered to the system for treatment; G_1 – is the dust mass flow rate delivered to the primary inlet of the CSF dust collector; G_2 – is the dust mass flow rate delivered to the secondary inlet of the CSF dust collector; G_3 – is the dust mass flow rate delivered to the bag filter for treatment; G_4 – is the dust mass flow rate at the outlet from the CSF dust collector; G_5 – is the dust mass flow rate at the outlet from the filter; G_6 – is the dust mass flow rate at the outlet from the system; K – is the proportion of the gas rate delivered to the bag filter for treatment; η_{con} – is the efficiency of the flow splitting in the dust concentrator; η_{CSF} – is the efficiency of CSF dust collector; η_f – is the efficiency of the bag filter.

Through the termwise division by the value of the dust amount delivered for treatment after the rotary dryer, we will reduce (1) to the non-dimensional form:

$$\overline{G}_1 + \overline{G}_2 + \overline{G}_3 = 1 \quad \eta_{con} \overline{G}_1 = 1 \quad G_3 = K(G_1 + G_2)(1 - \eta_{CSF}) - G_4 = 0 \quad (2)$$

$$G_4 + G_5 - G_6 = 0 \quad G_3(1 - \eta_f) - G_5 = 0$$

where

$$\overline{G}_n = G_n \times G_{total}^{-1}$$

The obtained system of six equations with six variables can be written in the form of the product = B , where:

$$B = \begin{pmatrix} 1 \\ 1 \\ K \\ 0 \\ 0 \\ 0 \end{pmatrix} \quad X = \begin{pmatrix} \overline{G_1} \\ \overline{G_2} \\ \overline{G_3} \\ \overline{G_4} \\ \overline{G_5} \\ \overline{G_6} \end{pmatrix} \quad A = \begin{pmatrix} 1 & 1 & 1 & 0 & 0 & 0 \\ \eta_{con} & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & 1 & 0 & 0 & 0 \\ 1 - \eta_{CSF} & 1 - \eta_{CSF} & 0 & -1 & 0 & 0 \\ 0 & 0 & 1 & 1 & 1 & -1 \\ 0 & 0 & 1 - \eta_f & 0 & -1 & 0 \end{pmatrix} \quad (3)$$

The solution of the obtained system has the form $X = A^{-1}B$, where A^{-1} – is the inverse matrix of the matrix A . The non-dimension quantity $\overline{G_6}$ characterizing the amount of dust contained in the cleaned air is determined as follows:

$$\overline{G_6} = \Delta_6 \times \Delta^{-1} \quad (4)$$

In this case, it is obvious that the quantity $\overline{G_6}$ being the ratio of the amount of the dust delivered for treatment and the dust leaving the aspiration system is numerically equal to the value of the total treatment efficiency η_{total} .

Figure 3 presents the model of the system of dust emissions treatment designed according to the scheme involving the treatment of the secondary low-dust flow in a bag filter (the first variant of the layout).

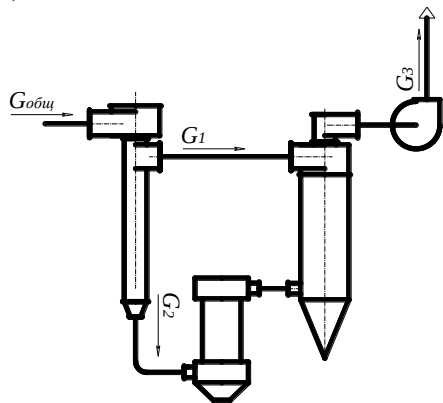


Figure 3. The model of the system of dust emissions treatment designed according to the scheme involving the delivery of the flow treated in the bag filter to the secondary inlet of the CSF dust collector.

Due to the simplicity of the scheme explained by the fact that the total efficiency of dust collection is determined by the operational efficiency of SCF dust collector obtained according to the data in [4, 5] as $\eta_{CSF} = f(L_2 \times L_{total}^{-1}, C_2 \times C_1^{-1})$ and the efficiency of the bag filter is adopted to be a constant value ($\eta_\phi = 0,98$, according to the catalogued data for the given dust), the value of the total operational efficiency of the system is determined directly on the basis of the listed initial data.

The objective of the conducted computational experiment was the obtaining of the comparative values of dust collection efficiency which characterize the systems of dust emissions treatment designed according to the suggested layout schemes, all other conditions being equal.

The results of the calculation are presented in the graphic form in figure 4. As it follows from the calculation results given in the graph, both layout schemes show approximately equal values of dust collection efficiency. In addition, both dependences are characterized by the maximum values observed within the variation range of the flow splitting efficiency $\eta_k = 66...80\%$. Upon exceeding the upper limit of the indicated range, the value of the total efficiency starts decreasing. The given fact can be presumably explained through the increase in the amount of fine particles which start getting into the upper inlet of the CSF dust collector due to the enhancement of the separation efficiency in the centrifugal dust concentrator.

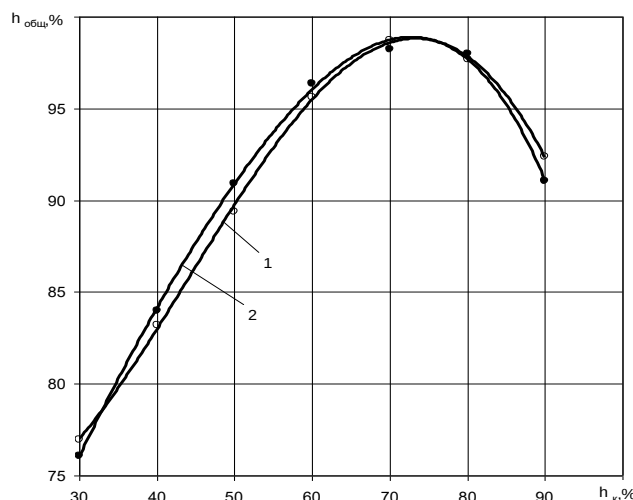


Figure 4. Dependences of the value of the total treatment efficiency in the first and the second variants of layout schemes on the value of flow splitting efficiency $\eta_{total}(\eta_k)$: 1 – the first layout scheme; 2 – the second layout scheme.

Due to the fact that the efficiency of fine fractions collection applying the inertial method is lower than that applying filtration, the total efficiency of the unit operation decreases.

Based on the idea that the second layout scheme has a more complicated configuration when compared to the first one and is characterized by similar values of emissions treatment efficiency as the preliminary analysis shows, a decision has been made on the irrationality of its use owing to considerable material and time inputs necessary for its practical implementation. Thus, for the realization of the suggested layout solutions, the first layout scheme is more rational.

Conclusions

- The use of CSF dust collectors for the treatment of dust emissions from mobile and portable asphalt mixing units has been justified.
- The analytical investigations of the operation of the designed layout schemes applying CSF dust collectors, dust concentrators and bag filters have been conducted.
- The data characterizing the influence of the flow separation efficiency in a centrifugal dust concentrator on the total efficiency of the presented layout schemes have been obtained.
- Based on the numerical experiment carried out, a conclusion has been drawn on the rationality of the use of the first layout variant as of the simplest and most easily producible at the equal values of total efficiency of dust emissions treatment.

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