Experimental studies of aspiration and pneumatic conveying systems at the enterprises manufacturing rubber products

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Abstract. The article is devoted to the study of aspiration systems and pneumatic transport in the workshops for the rubber products manufacturing. The methods for controlling dust from the rubber production plants to create favorable conditions in the operators’ working areas have been developed. A description of the existing and proposed schemes of pneumatic conveying systems has been presented. The new switch valves for pneumatic conveying systems have been considered.

1. Introduction
The increase in the growth rate of the machine-building complex, the equipment modernization and the sanitary and epidemiological legislation tightening require the organization of a detailed approach to the aspiration and pneumatic conveying systems’ design at the industrial enterprises. In turn, the engineering protection systems (dust-exhausta systems) do not localize the dust emission from the sources for various reasons, as a rule, comprehensively. In the process of transportation and processing the raw materials, dust enters the working zone air, moreover, its concentration can be from 0.5 till 20 g/m³ depending on the dust properties, which significantly exceeds MPC [1].

Industrial aerosols have a high concentration and varying degrees of dispersion, particle microstructure and chemical composition. Currently, the pathogenesis of dust effects on the body of a worker is studied quite deeply and in detail. Industrial aerosols can be accumulated in organs and tissues, causing more pronounced pathomorphological lesions of internal organs, and also, having a long half-life, are extremely difficult to excrete from the body [2-5]. The main exposure effect to the particles PM10 and PM2.5 inhalation penetration into the upper respiratory tract and lungs on the human body, which leads to damage to the pulmonary tissue, causes respiratory diseases [6, 7]. Thus, the aspiration and pneumatic conveying systems’ improvement at the enterprises manufacturing rubber products is important and satisfies the conditions for improving environmental safety and labor protection.

2. Systems of pneumatic transport and aspiration in the rubber products’ manufacturing
The technological process for the rubber products manufacturing starts with the preparatory department, where all the components that make up the molding composition, are prepared. In the preparatory workshop rubber compounds for various purposes are produced. A rubber compound is a multicomponent system containing 8 to 10 different parts. The composition of the latter includes such raw materials as synthetic rubber and fillers (carbon black, kaolin, etc.). The prepared components in certain proportions according to the pneumatic conveying system are put into the tanks of the production
workshop, after which the mixture enters the mixing devices in the right amount. The final prepared mass from the mixing devices is unloaded into the feeder and sent to the production conveyor. The dust emission process in production is associated with the raw materials’ re-loading. So, during the mixture transportation in the capacity of the production hall, a significant amount of dust is released, exceeding the maximum permissible norms in the working area. In the presence of air flows in the workshop room, dust spreads throughout the room. This is confirmed by the experimental equations establishing the dust concentration dependence in the air of the working area and the dust deposition intensity [8]. Dust distribution throughout the department is extremely unacceptable from the point of view of work safety, sanitary and epidemiological requirements, and therefore it is necessary to develop the measures that exclude the emissions into the workshop’s working area and atmosphere.

The main hazards in the working area of the workshop is the dust released during the operation of cyclones. Figure 1 shows a diagram of the rubber mixture dust pneumatic transport and the aspiration system from cyclones.

![Diagram of pneumatic transport and aspiration system](image)

**Figure 1.** The existing scheme of pneumatic conveying of the rubber mixture dust of the material and the dust-exhaust system: 1 - centrifugal fan; 2 - switch valve; 3 - cyclone; 4 - valve box; 5 - centrifugal fan; 6 - pressure filter

As it can be seen in Fig. 1, the pneumatic transport sections’ length to cyclones is different. As a result of this, the resistance values of the sections are different, since:

$$P = \lambda_{cm} \cdot \frac{l}{d} \cdot \frac{V^2}{2g},$$

(1)

where $\lambda_{cm}$ - is the mixture friction coefficient; $l$ – is the reduced length of pneumatic conveying pipeline taking into account linear and local pressure losses, m; $d$ – is the pipe diameter, m; $V$ – denotes flow rate, m/s$^2$; $g$ - is the gravity acceleration, m/s$^2$; $P$ – shows the total pressure loss, kg/m$^2$.

For pneumatic transport, a centrifugal fan is used, which is known to have a gentle characteristic. This leads to the fact that in the case of even a slight change in the network resistance, the fan performance changes dramatically. Therefore, a different amount of air will flow to each of the cyclones through the pneumatic transport.

Separating the dust from the rubber mixture in a cyclone, dusty air is cleaned by means of an aspiration system in a bag filter and emitted by a centrifugal fan into the atmosphere. One of the measures aimed at reducing the dust load on bag filters is the installation instead of the cyclones devices on the counter swirling flows [9-11].
If the amount of air entering the cyclone through pneumatic transport is denoted by \( Q_1 \) and the amount of air removed from the cyclone and the hopper by the aspiration system is denoted by \( Q_2 \), there should be some optimal ratio of these values:

\[
K_{\text{opt}} = \frac{Q_1}{Q_2}.
\]  

(2)

At \( K<K_{\text{opt}} \) a part of the air with the rubber mixture dust enters the discharge hopper, which leads to the excess pressure emergence in the hopper, as a result of which dust will be knocked out into the working area of the workshop. At \( K>K_{\text{opt}} \) a part of the rubber dust with air will be sent to the dust-exhaust system and the filter will become clogged. Therefore, at the optimal value \( K=K_{\text{opt}} \) there should be a vacuum in the hopper, but not so large that it can cause the filter clogging.

With the existing pneumatic conveying scheme and aspiration system, not only the different amount of air flow to each cyclone \( Q_1 \) can be noted, but also a different amount of \( Q_2 \), removed from the cyclones and bins using an aspiration system. This happens for the same reason as in pneumatic transport: the sections’ length is different; therefore, their resistance is also different and with a gentle characteristic of the centrifugal fan installed at the system outlet, the amount of air removed from the cyclones is different.

Thus, it turns out:

\[
K_1 \neq K_2 \neq K_3 \neq K_4 \neq K_{\text{opt}}
\]

where \( K_1, K_2, K_3, K_4 \) – are the actual values; \( Q_1/Q_2 \) – are true for each of the four cyclones.

The bunkers are loaded with the rubber mixture one at a time, that is why the valves and switches are installed in the pneumatic conveying system and on the dust-exhaust system. A valve - switch is a flapper type valve installed in a standard tee in such a way that when it is turned to the extreme positions, one of the tee branches overlaps. During the long-term operation, it turned out that such valves do not work satisfactorily. The reason is that the branches do not completely overlap with the valve and air leaks occur in the gaps, moreover, the amount of leakage for each valve changes over time. This leads to the fact that the quantity \( K \) for each of the cyclones changes over time, i.e. \( K_1=f_1(t) \), \( K_2=f_2(t) \), \( K_3=f_3(t) \), \( K_4=f_4(t) \),

3. The aspiration and pneumatic transport systems’ improvement

The analysis of the dust emission causes on the first production floor has identified the need for a number of measures to prevent dusting.

Firstly, it is necessary to create such an operation mode of the pneumatic conveying system and the dust-exhaust system on the first production floor, that when loading the ingredients in the loading hoppers there is some rarefaction. For this, it is required by experiment to determine the optimal value of \( K \) and to achieve the equality of the ratio \( K \) for all cyclones, i.e.: \( K_1 = K_2 = K_3 = K_4 = K_{\text{opt}} \).

This condition can be provided by changing the characteristics of the pneumatic transport network and the aspiration system. The characteristic is known to be a parabola:

\[
P = C \cdot Q^2
\]

(3)

Having completed the transformation of formula (1), representing the speed through the flow rate and area, we obtain:
Secondly, it is necessary to achieve a constant in time value of the $K$ ratio for all cyclones. This condition should be ensured by the reliable operation of the switch valves.

Thirdly, it is necessary to organize swirling flows in horizontal sections of aspiration networks that are subject to the dust deposits’ formation [12].

Figure 2 presents the proposed scheme of pneumatic transport of the rubber compound. This circuit has a number of distinctive features:

1. The branches of the pressure network to the unloading cyclones are of the same length and the branches of the aspiration system from the cyclones are also of the same length.
2. The valves-switches for alternative pressure are installed in the pressure network to the cyclones-unloaders.
3. In the aspiration network, one valve box is installed instead of 3 switch valves.
4. An exhaust filter is installed in the exhaust network instead of the intake filter.

\[
C = \lambda \cdot \frac{l}{d} \cdot \frac{\gamma}{2g} \left( \frac{1}{3600 \cdot 0.785d^2} \right)^2 .
\]

Alignment along the length of sections of pipelines of the pressure head network while maintaining the same diameter ensures equal pressure losses on the way from fan 1 to each of the cyclones. Therefore, each of the cyclones receives the same amount of air $Q_1$. Similarly, the accepted alignment of the pipeline sections of the suction network, while maintaining the same diameter, leads to the fact that the same amount of air is removed from each cyclone by the fan 5 $Q_2$. Ratio $K_{opt} = \frac{Q_1}{Q_2}$ for each cyclone is a constant value, which indicates the operation of all cyclones in the same mode.

In pneumatic transport installations, non-working branches should be reliably disconnected from the network while maintaining tightness. To disable idle branches, a switch valve design is proposed, which is a tee, the branches of which are alternately blocked by the rotary dampers. Each damper is a round metal disc with a rubber gasket. The damper is pivotally mounted on a pivot arm driven by a pneumatic cylinder. There is one pneumatic cylinder per lever. In the closed position, the damper fits snugly against
the pipe end due to the rubber gasket. When opening, the lever is rotated by an angle 80-85° and held open by the pneumatic cylinder. In the closed position, the damper is held by a counterweight.

Summary
The conducted experimental studies showed that the pneumatic transport system and the dust-exhaust system work reliably in the studied modes. In the switch from the branching point to the closed damper, the rotational movement of the mixture and accumulation of the transported material does not occur. In the closed position, the damper reliably blocks the pipe branches. When the pipe is quickly closed, rubber dust particles do not enter the cutoff branches. When the branch is slowly closed, dust particles fall into the place of the shutter contact with the pipe end. However, even in this case, a reliable disconnection of an idle branch occurs. Thus, the proposed switch design for pneumatic transport of the rubber mixture is fully functional.

According to the results of experimental studies in laboratory conditions, using the proposed pneumatic conveying schemes, valve box, new switch valves, air dust reduction in the working area at 70% has been found.

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