Improving the schemes for ash removal from hopper ash collectors based on modeling

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Abstract. Various ash removal schemes from the hopper ash collector to such transportation devices as hydraulic ash disposal channels, are analyzed. The drawbacks of these schemes are: high flow rates of flush water, gas flows through common ash gutters between bunkers of different pressure, and clogging of ash flows. The paper considers the invention and its introduction, which will eliminate or reduce these drawbacks by increasing the reliability of the circuits and centralizing the discharge of ash. The high efficiency of the invention under consideration is illustrated by the example of its practical use in the Galachinsk boiler house situated in the territory of Bratsk. To determine the design and operational parameters of the above mentioned invention its mathematical model has been developed based on the balance of forces acting in it (on the continuous gate). With the help of the obtained model, the structural and operational parameters of the device are calculated in three possible variants of its implementation. In these cases, the number of sections of different pressure changes and the presence of a periodic action shutter is taken into account. The determined parameters are the maximum and minimum heights of the ash column, the mass and the position of the load of the continuous gate. Ash collector performance indicators affecting these parameters have been identified. An ash collector of the TsBR-150U-1280 type, which has ash bunkers with three different values of vacuum, is accepted as an example. On the basis of the developed model, an algorithm has been compiled for calculating the design and operational parameters of the device under consideration during its design.

Various systems for cleaning gases from dust or ash and the subsequent removal of the captured material to the means of transportation are widely used in power engineering and industry. Therefore, issues of increasing the reliability and efficiency of these systems remain important. Modern publications of domestic and foreign authors on the problems of improving these systems are widely known [1-3].

There are known schemes for removing ash (dust) from the hoppers of the ash collecting plant.

1. From each hopper, ash is discharged along the chute to the batch and continuous valves, the mixer, the vehicle, which can be, respectively, a gate, a flashing light, a flushing device and a hydraulic ash removal channel [4]. The disadvantage of this scheme is that with an increase in the number of bunkers, the number of intermittent and continuous valves, mixers, increases, respectively. It causes an increase in consumption of the transporting medium and complicates the work of operating personnel.

2. Ash from hoppers is discharged along the chutes into the common chute. Then the ash is fed centrally to the mixer, from which the water-shale pulp is discharged into the hydraulic ash disposal channel. In front of the mixer, a periodic repair valve is usually installed [4]. The disadvantage of this
scheme is that in the presence of different pressures in the bunkers, gases flow together with the ashes through the chutes and the common gutter. This leads to a sharp drop in the efficiency of the ash collector. Different pressures can be created in the ash bunkers of different ash collecting stages arranged in series along the movement of the gases being cleaned, especially at different types of these steps.

If the chutes from the hoppers are brought into the common gutter at an angle below the ash pillar, a stop (or delay) of the ash is possible. Then the chutes are clogged (if the chutes are put into the gutter at the angles lesser than the natural slope in repose state).

To eliminate these drawbacks, a device has been developed for implementing the following technical solution: chutes from hoppers under various pressures are brought to the continuous gate coaxially and set below the upper level of the ash pillar. Ash pillar prevents the flow of gases between the hoppers (see figure). To improve the ash flow tracing, chutes are made of two sections: 1. The inclined one from the hoppers to the vertical axis passing through the continuous gate; 2. The direct one from turning chutes to a continuous shutter.

The turning of the chute is performed over the ash pillar and the ash in the chute constantly moves until it falls to the surface of the ash pillar. It will allow designing the inclination angles of the chutes close to the angles of ash repose in a state of motion, which can increase the centralization of ash removal. The described device is recognized by the invention [5].

The introduction of this device in the Galachinsky District boiler house of Bratsk for centralized discharge of ash from ash collectors of the TsBR-150U-1280 type under various pressures allowed replacing 15 ash-removing devices by three and increasing the ash collector's efficiency over the heating period by 13% [6] (by eliminating the flow of gases between bunkers).

From the above it follows that an important role in the operation of the device in question is played by such a parameter as the calculated height of the ash pillar.

In the literature [4], the height of the ash pillar (m) is determined using the following formula

\[ H = \frac{S}{g\rho_b} + 0.1, \]  

(1)

S is the vacuum in the hopper, N/m²; g is the gravitational acceleration, m/s²; and \( \rho_b \) is the bulk density of ash or dust, kg/m³;

The formula allows us to estimate the height of the ash pillar, which is necessary to exclude air suction. However, the formula does not determine the actual height of the ash pillar under operating conditions, since it does not take into account the influence of the load (counterweight) of the flasher.

Initially let us consider the device, provided that the chute is directly supplied to the valve. Let us make the balance equation of forces in the conditions of equilibrium acting on the flasher (see figure)

\[ \sum N_{h_i} + N_1 \left( \frac{b}{a} \right) = N_{a,p}, \]  

(2)

\( \sum N_{h_i} \) is the the sum of forces attracting the valve flashers to the chute due to the pressure difference in the environment and ash hoppers, H; \( N_{h_i} \) is the the force of gravity of the load, which presses the valve flashers to the chute through the lever, H; a, b are the distances from the centers of gravity of the flasher valve and load to the axis of rotation of the lever, m; \( N_{a,p} \) is the gravity of the ash pillar, opening the valve flashers from the gutter, H.

It can be seen from the figure that the vertical sections of chutes coaxially connected to the ash pillar divide the device (common gutter) into sections. The number of sections (i) corresponds to the number of hoppers of different pressure, but several hoppers of the same pressure can be connected to each section.
Figure 1. Device for centralized discharge of ash from several bunkers under different pressure: 1 - continuous shutter (flashers); 2 - periodic action shutter (gate); 3 - chute; 4 - bunker; 5 - ash-water mixer; 6 - channel of hydraulic ash removal; 7 - coaxial input chutes; 8 - valve; 9 - lever; a, b - distances from the centers of gravity of the flashe r valve and the load to the axis of rotation of the lever; $\sum N_{b_i}$ - the sum of forces attracting the flashing valve to the gutter due to the pressure difference in the environment and ash hoppers; $N_l$ - the force of gravity of the load; $N_{a.p.}$ - gravity of the ash pillar.

The force acting in each section can be determined by the formula

$$N_{b_i} = S_i \cdot F_i,$$

where $S_i$ is the negative pressure in the i section (bunker), N / m$^2$; and $F_i$ is the cross-sectional area of the i section, m$^2$.

The cross-sectional areas of sections, representing the difference in areas of circles of different diameters can be calculated by the formula

$$F_i = \frac{\pi}{4} \left(d_{1i}^2 - d_{si}^2\right),$$

where $d_{1i}$ and $d_{si}$ are the larger and smaller section diameters.

Gravity $N_e$ and $N_{a.p.}$ can be expressed as product of the respective masses and the acceleration of free fall. After substituting all components in (2), it is possible to express the ash mass of the ash pillar in all sections by the formula

$$\sum m_i = \frac{1}{g} \sum \left(S_i \cdot F_i \right) + m_l \frac{b}{a},$$

where $m_l$ is the weight of the flasher load, kg.

The mass of ash in the i-th section can be calculated by the formula

$$m_i = \kappa_i \cdot \sum m_i,$$

where $\kappa_i$ is the proportion of ash entering the device from the i-th bunker, determined from the analysis of the operation of the ash collector.

The height of the ash pillar in the chute of the i-th section can be determined by the formula...
The starting point of $H_i$: can be considered the midpoint of the segment between $d_1$ and $d_s$ section.

Formulae (2) - (7) represent a mathematical model for determining the design parameters of the device in question, provided that the chutes from the ash bins are supplied directly to the flashing valve.

With the help of the represented model, we will determine the parameters of the device in question as applied to a battery cyclone of the TsBR-150U-1280 type. Scheme of the ash collector and features of its work can be found in the literature [1, 6, 7].

Calculations were initially performed for two options for the inclusion of the device in question into the ash removal scheme. In the first implementation, the device contains two sections Each of them is connected by chutes with chambers of dusty gases and ash chambers, respectively. In the second embodiment, the device contains three sections, two of which are connected to the above chambers, and the third one - to the ash hoppers of the group of TsN-15 cyclones. The use of the device in the second embodiment could reduce the number of ash-washing machines on the ash collector to two, compared with the first version (with three devices). The calculation results are summarized in table 1.

**Table 1.** Estimated design and operational parameters of the device for centralized discharge of ash from several hoppers under various pressures.

| Parameters                          | Section No. | Name     | With two sections | With three sections | With three sections and a periodic shutter |
|-------------------------------------|-------------|----------|-------------------|---------------------|------------------------------------------|
| Vacuum in the hopper (N / m²):      | 1           | $S_1$    | 500               | 500                 | 500                                      |
|                                     | 2           |          | 1000              | 1000                | 1000                                     |
|                                     | 3           |          | -                 | 1200                | 1200                                     |
| Outer and inner diameters of chutes (m) in sections: | 1           | $d_o/d_i$ | 0.1 / 0.096       | 0.1 / 0.096         | 0.1 / 0.096                              |
|                                     | 2           |          | 0.15 / 0.146      | 0.13 / 0.126        | 0.13 / 0.126                             |
|                                     | 3           |          | -                 | 0.15 / 0.146        | 0.15 / 0.146                             |
| Cross-sectional areas (m²) in sections: | 1           | $F_i$    | $7.23 \times 10^{-3}$ | $7.23 \times 10^{-3}$ | $7.23 \times 10^{-3}$                  |
|                                     | 2           |          | $8.9 \times 10^{-3}$ | $4.61 \times 10^{-3}$ | $4.61 \times 10^{-3}$                  |
|                                     | 3           |          | -                 | $3.45 \times 10^{-3}$ | $3.45 \times 10^{-3}$                  |
| Ash mass in sections, kg            | $\Sigma m_i$ | 16.28    | 16.26             | 4.97                |
| The proportion of ash entering the device in sections: | 1           | $K_i$    | 0.17              | 0.09                | 0.09                                      |
|                                     | 2           |          | 0.83              | 0.455               | 0.455                                     |
|                                     | 3           |          | -                 | 0.455               | 0.455                                     |
| Height of the ash pillar (m) in sections: | 1           | $H_i$    | 0.13              | 0.07                | 0.02                                      |
|                                     | 2           |          | 0.51              | 0.54                | 0.16                                      |
|                                     | 3           |          | -                 | 0.72                | 0.22                                      |
| The total height of the ash pillar (m) in sections: | 1           | $H_i^f$  | 0.13              | 0.07                | 0.245                                     |
|                                     | 2           |          | 0.51              | 0.54                | 0.385                                     |
|                                     | 3           |          | -                 | 0.72                | 0.445                                     |

a) The bulk density of ash ($\rho_b$) is taken as 3000 kg / m³.
b) The lengths between the axis of rotation of the flasher lever and the centers of gravity of the valve and the flasher weight (a, b), respectively, are equal to each other.
c) The weight of the flasher cargo ($m_1$) in variants 1 and 2 is taken as 15 kg.
d) The calculated masses of cargo and ash in the 3 version are: $m_c = 11.29$ kg, $m_1 = 14.99$ kg.
e) Part of the height of the ash column $H_i$ is taken as 0.225 m.
The following conclusions can be drawn from the analysis of the calculation results. Only a small part of the mass (height) of the ash pillar compensates for the effect of vacuum in the bunkers, and most of it compensates for the mass of the load (compare 16.28 and 15 kg).

The calculated heights of the ash pillars in sections are very different and depend mainly on two parameters: the proportion of ash \( k_i \) entering the corresponding section and the sectional area of the section \( F_i \).

In practice, batch valves (rotary valves or retracted gates) are usually installed above the continuous gate. In this case, chutes from the hoppers can be brought to the ash pillar only above the specified batch valve. In this case, the full height of the ash pillar (see figure) can be determined by the formula

\[
H'_i = H_v + H_i, \tag{8}
\]

\( H_v \) is the part of the full height of the ash column between the valve flasher and the end of the leak determined by structural considerations; \( H_i \) is the part of the full height of the ash pillar attributable to the chute (section).

In the case of installing a rotary round valve, the value of \( H_v \) can be estimated as:

\[
H_v = 1.5 \ d_v, \tag{9}
\]

\( d_v \) is the internal diameter of the valve (gutter).

To determine the value of \( H_i \), formulae (2) - (7) can be used, but first it is necessary to find the mass of the load. To do this, on the basis of (2) let us write the balance equation

\[
\sum m_i + m_v = \frac{1}{g} \sum (S_i \cdot F_i) + m_i \frac{b}{a}, \tag{10}
\]

\( m_v \) is the mass of ash in the ash pillar with height \( H_v \).

The parameter \( m_c \) can be determined from the formula (7) by taking \( H_i = H_v \) and \( F_i = F_g \) (gutter cross-sectional area).

From the formula (10) it is possible to express one unknown parameter, for example, \( m_c \) with other specified or found indicators. In this case, the ash mass in the \( \Sigma m_i \) sections should be expressed as a part of \( m_v \), which is necessary to exclude gas flows between the sections (chutes).

\[
\sum m_i = n \cdot m_v, \tag{11}
\]

\( n \) is the fraction of the mass reserve (height) of ash in chutes; taking into account formula (1) this share can be determined by the formula

\[
n = \frac{0.1}{H_v}, \tag{12}
\]

Further, the parameters \( m_i, H_i, H'_i \) are determined on formulae (6), (7), (8):

According to the described model (2) - (12), the parameters of the device under consideration were calculated with the inclusion of a periodic action gate and three sections. The results of the calculations are presented in the table (option 3).

Comparing \( H'_i \) variants, it can be concluded that in the 3rd variant, the ash is distributed over the sections more evenly than in the 1st and 2nd ones. Consequently, the overall dimensions of the device in the 3rd variant can be smaller than in other variants. This result can be explained by the following factors. In the 1st and 2nd variants, the weight of the load is assumed to be 15 kg (flashers can be completed with such loads), and in the 3rd it is calculated according to the specified parameters \( d_v, K_v, S_v \).

Consequently, the value of \( m_i \) in the 1st and 2nd variants contains a larger stock \( \Sigma m_i \) than in the 3rd variant.
Based on the above analysis of the operation of the device in question, the following algorithm for its design is proposed.

1) The possibility of supplying ash from various hoppers to the device under consideration is evaluated, provided that the slope angles of leakage are greater than the angles of repose. 2) The ash consumption from hoppers and its share in the total consumption delivered to the device ($k_i$, taking into account the efficiency of the ash collector) are determined. 3) The operational and design parameters are refined and set: diameters and type of continuous and batch valves, as well as vacuum in hoppers. 4) Further calculations are performed using the following formulas: (9), (12), (7), (11), (6), (10), (8). 5) The overall dimensions of the device are determined: vertical sections of chutes should begin above the ash pillars ($H_i^f$) and end at the height of $H_v$; the limit positions of the cargo flashers, determined by the ratio of the parameters (b/a), must correspond to the maximum and minimum values $H_i^f$ and $H_v$, respectively.

It should be noted that the presented model can be used to calculate the parameters of the device under consideration for any number of sections ($i$), including if $i = 1$, that is, for existing schemes.

Findings
1. A device for centralized discharge of ash from several hoppers under different pressure has been considered. Its introduction will significantly improve the efficiency of ash removal schemes.
2. A mathematical model (2)-(12) and an algorithm for calculating the design and operational parameters of the considered device have been presented.
3. The results of calculations of these parameters for the three possible options for its implementation on the ash collector of the type TsBR-150U-1280 have been presented.

References
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