Research on structure of a ash-slag pulp and its influence on pipelines’ attrition of a thermal power plants’ hydraulic ash removal system

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Abstract. One of the key characteristics, affecting intensity of slurry pipelines’ attrition, is the abrasiveness of the transported material. It depends on the content of silicon oxides, a form and fineness of ashes particles. According to input data, it is figured out that different types and grades of coals with different chemical properties, fractional composition and coal fineness were incinerated at different times on HTPP-3. Because of it the attrition is result of different types’ transportation of ashes with various abrasive properties, with various fineness, density and chemical composition. Calculation results of pulp pipelines’ specific attrition at transportation of ash-slag pulp on HTPP-3 are given in this work.

1. Introduction

One of the main problems of pulp pipelines operation is the attrition, which affects the reserve substance period and reliability of equipment operation. Due to the pipes wear of hydraulic ash removal system the longevity decreases, there is a need in forced idle times, caused by fistulas in pipelines, therefore there can be serious financial losses from ecological penalties, because of unauthorized pulp dumping on a soil, the cost efficiency of ash-slag pulp’s transport, the bound to increase in pipes diameter, owing to wall thickness’ thinning of pulp pipelines worsens.

Development of protection technology of pulp pipelines will allow to reduce the frequency of the emergency shutdowns significantly. It will lead to positive economic effect by the considerable cut in expenditure of repair fund and penalties payment to supervisory authorities.

2. General information about abrasive properties of ashes

The attrition of systems’ pipelines of a hydro-ash-slag removal of thermal power plant, in general, depends on properties of ashes, material of pipes and conditions of transportation [1].

Abrasive properties of the transported ashes are generally caused by its physic-mechanical properties and chemical and mineralogical structure.

Physic mechanical properties of ashes are defined by density and fineness of material, particles’ form, polydispersity of stream. The chemical and mineralogical structure is caused by existence SiO2, Al2O3, Fe2O3, CaO, MgO and etc. in ash and also their connections at various phase changes.

2.1. Form of particles
The ashes, transferred by water flow in the systems of hydraulic ash removal, are polydisperse material and contain a large number of particles, which have various forms – from spherical to lamellar, the shell-viewed and other more difficult configurations. In the presence of sharp edges grit influence a surface with its microcutting and shaving removal. Thus, the form of particles, which is characterized by \( k_i \), crest factor has the considerable impact on abrasive properties of ashes. It is quite easy to describe a form of particles qualitatively, but it is difficult to express quantitatively. Here there is an important question of \( k_i \) definition for particles group of different forms. According to [2] particle, for example, ash microspheres can have the form, rather close to spherical. The ungeometrical particles, with a large number of surface asperities, have various static and dynamic characteristics in comparison with particles of the correct form. During particle size decrease the value of their form decreases. Thus, there is a connection between the size and a form of particles [3].

Often the term "sphericity" is applied to definition of a particles form. The sphericity of particles \( \psi \) according to [3] is defined as the relation of a sphere surface of the same volume as a particle to a specific surface area of a particle.

The more \( \psi \) deviates 1.0, the particle is less spherical. According to [4], depending on a surface form and nature, grain of the irregular form can be carried to one of the following groups: roundish particles with a smooth surface; roundish and cylindrical particles with a rough surface; particles with breaks and sharply ungeometrical cracks.

According to [5] crest factor is the relation of ungeometrical particle surface \( S \) to a surface of a sphere \( S_0 \), which volume is equal to the volume of an aspheric particle.

According to [6] in case of the description of particles material’ properties with the irregular shape, the concept of a geometrical crest factor \( k_i \) is applied. The coefficient \( k_i \) is particle surface \( S \) relation to a surface \( S_0 \) sphere, isometric on volume basis. There is an alternative to it, it’s a reciprocal value, which is called coefficient of sphericity \( \psi \), \( \psi = 1/k_i \).

In case \( k_i \geq 1 \), \( 0<\psi \leq 1 \); for spherical particles \( k_i = \psi = 1 \). For ungeometrical particles \( k_i \) and \( \psi \) are defined experimentally.

For definition of a crest factor of particles representative test it is necessary to have fractional composition of the studied test with crest factors of particles on groups \( k_{i1} \) and \( k_{i0} \) fractions. Then the average crest factor \( k_f \) will be equal:

\[
k_f = \frac{k_{f1} \cdot m_1 + k_{f2} \cdot m_2 + \ldots + k_{f0} \cdot m_0}{100%}
\]  

\( m_i \) to \( m_i \) – the substance by i of particles fractions, % of weight.

2.2. Density and fineness of material

During consideration of properties of abrasive material particles, it is possible to draw a conclusion that firm, dense and large particles cause a bigger attrition [7-9]. According to [10], it is possible to classify ash-slag materials (except for liquid slag) as abrasives of shallow and average fineness, their increase of the linear dimensions causes proportional increase in wear intensity of structural materials

2.3. Polydispersity (fractional composition of material).

Fractional material composition is a characteristic of fineness of its pieces. Particle sizes of a fly ash considerably depend on a degree of fuel grinding fineness and technology of its combustion. The polydispersity is characterized by fractional composition, which shows what share or percent of weight are made by particular particles or groups of particles in all analyzed test.

Proceeding from definition that the material polydispersity is a particles inhomogeneity on fineness or a different factionalism, the polydispersity coefficient \( k_d \) depends on the average fineness of material, which is determined by a formula according to [11]:
The polydispersity of material also affects the size of particles median diameter in distribution. Thus, for coefficient determination of a material polydispersity, it is possible to use the relation of the average fineness of particles $d_0$ to the median diameter of particles $d_{med}$:

$$k_d = \frac{d_0}{d_{med}}$$ (3)

We consider that $k_d > 1$. For monodispersional environments $k_d = 1$, for the polydispersional environments $k_d > 1$.

With rise of large fractions content percentage the average fineness of the transported particles increases, owing to that the size of pipelines attrition, with level relation to transportation speed, increases.

2.4. Chemical and mineralogical structure

The principal component, causing an attrition of pipelines, is SiO$_2$. Influence of other firm connections, leading to pipe wall attrition, is negligible.

It’s more convenient to define assessment of the impact of SiO$_2$ maintenance in the transported material on attrition not with percentage, but with coefficient of SiO$_2$ - $k_{SiO_2}$. It is bound to the fact that there are data from various sources on pipelines attrition and other inventory at transportation of various abrasives, containing silicon oxides in different quantity. During the analysis of these data it was figured out that the most intensive attrition is observed with other things, being equal in case of quartz sand’s air lift [1]. $k_{SiO_2}$ is equal to the relation of SiO$_2$ weight percentage in the transported material to SiO$_2$ weight percentage in quartz sand:

$$k_{SiO_2} = \frac{\text{содержания SiO в транспортируемом материале}}{\text{содержания SiO в кварцевом песке}}$$ (4)

2.5. Coefficients of absolute and relative abrasiveness of material

The coefficient of absolute abrasiveness of ashes $f_a$, [sq.m/kg], is determined by a formula [19]:

$$f_a = 801,8 \cdot 10^{-14} - 1,945 \cdot 10^{-14} \cdot R_{90} + 0,833 \cdot 10^{-14} \cdot R_{90}^2$$ (1)

R90 is a sieve residue of 90 microns, %.

3. Input data for a research of ashes structure and properties, which are formed at coals combustion on HTPP-3

In figure 1. data on coal consumption are given in HTPP-3 from 1996 to 2017.

From all incinerated coals more than 1% are incinerated: neryungrinsky coal, neryungrinsky industrial product, the ural coal, the kuznetsk coals and the chinese coal, which are rather close on the main characteristics. Neryungrinsky coal is in project. Neryungrinsky coal and neryungrinsky industrial product are very close in the characteristics. Further the results of test analyses of neryungrinsky coal ashes, which are selected on ash-slag landfill of HTPP-3 in July, 2018, received at a research of chemical and mineralogical and fractional structures and also the information about chemical and mineralogical and fractional structures and properties of the ash, specified coals from scientific and technical sources of information, were used.
4. Research of fractional composition of ash-slag

The average analysis of researches' results of fineness, particles fractional composition and form in tests No. 1-3. Fineness of ashes particles in tests No. 1-3 changes from 8.2 to 368.1 microns, however, the ground mass of particles measures from 20 to 180 microns. Average diameter of particles is equal to 112.5 microns in tests No. 1-3. The relation of the maximum size to minimum makes 1.2 in tests No. 1-5. Thus, the crest factor of ashes particles in the specified tests makes 0.83. Particles with $W_k$ with about 1.0, have spherical shape.

While comparing influence of particles fineness on an attrition of pulp pipelines it must be noted that larger particles of ashes lead to the raised attrition of pulp pipelines in comparison with shallow. It is caused by the fact that large particles of ashes represent a mineral part of coals most often, which have a decisive influence on an attrition of pulp pipelines due to chemical and mineralogical structure of particles, their form and, the most important, traveling speeds of particles in a pulp. Shallow particles of ashes in a water boundary layer have very small speed and move in a wall layer of pulp pipelines mostly laminarly. Large particles of ashes move turbulently due to collisions with slag particles owing to their different traveling speeds.
HTPP-3 ashes have the expressed polyfractional properties. The polyfactiousness of ashes’ particles in the transported pulp has significant effect on an attrition of pulp pipelines, which has a level relation to critical speed of a stream. This feature leads to a possibility of group measure installation system work with slushing of pulp pipelines at ash-slag transportation with the high content of silicon and low content of calcium, especially at above-zero temperatures of fresh air.

5. Determination of ash-slag pulp abrasivity

There is a large number of the term definition "abrasiveness coefficient" of material. The coefficient of abrasiveness depends on density, hardness, size and form of ash particles, an angle of attack and metal wear resistance [12], mineralogical composition of dust, durability, hardness, form, density and particle sizes and in each case has to be defined experimentally [13]. The coefficient of the material relative abrasiveness depends on the content of silicon, fineness of particles and their form. Influence of silicon content on ashes abrasiveness is more significant, than influence of material fineness and a grains form. It is considered in the form of an exponential relation with formula for coefficient determination of the ashes relative abrasiveness. Thus, according to the Research organization Moscow Energetic Institute model for materials of shallow and average fineness it is possible to consider that the coefficient of the material relative abrasiveness is equal:

\[ k_a = \frac{k_{SiO_2} \cdot k_{d_{cp}}^{0.5}}{k_f^{0.5}}, \]

\[ k_{SiO_2} \] – coefficient of the SiO2 relative substance; \( k_{d_{cp}} \) is the attitude of the ashes average fineness to the average fineness of sand; \( k_f \) is a crest factor of particles.

Calculation results of ashes abrasiveness size of coals in HTPP-3 are given in tab. 1.

| Material                    | SiO₂, % | \( k_{SiO_2} \) | \( d_{cp} \), micron | \( k_{d_{cp}} \) | \( k_f \) | \( k_a \) |
|-----------------------------|--------|-----------------|-----------------------|-----------------|----------|---------|
| Ashes of neryungrinsky coal | 54,7   | 0,558           | 112,5                 | 0,193           | 0,83     | 0,268   |
| Ashes of kuznetsk coal      | 60,0   | 0,612           | 61,0                  | 0,104           | 0,83     | 0,217   |
| Ashes of urgalsky coal      | 66,0   | 0,673           | 59,1                  | 0,101           | 0,83     | 0,235   |

According to calculation, most abrasive materials are ashes of neryungrinsky coal, although silicon substance is less in it, than in ashes of kuznetsk and urgalsky coals. It is bound to the fact that the average fineness of test of neryungrinsky coal ashes surpasses fineness of kuznetsk and urgalsky coals ashes twice, determined according to fractional composition by reference data [14]. According to the data of fractional composition, given in [14] estimated average fineness of neryungrinsky coal ashes is 51.9 microns, it is more than twice less than estimated value in the studied test of neryungrinsky coal.

6. Determination of specific abrasive wear of the pulp pipelines

In order to define metal attrition of the pulp pipeline wall while moving ash pulp, it is necessary to have data on transportation conditions (speed transportation of a pulp, its concentration). Because of absence of above-stated data, to assess an attrition of pulp pipelines on the basis of [15], we will accept that the speed of transportation of ash-slag in industrial conditions is from 1.2 to 1.8 m/s. Weight concentration of hydromix during removal of ashes or ashes and slag composition is 5 … 10%.
Specific pipeline service period to an average wear of pipes wall thickness on 1 mm, year/mm, it is possible to determine with a formula from [10]:

\[ T_i = \frac{K_{an} \cdot n \cdot \psi \cdot k_a}{k_u \cdot v_{cp}^{2.3} \cdot S_{cp}^{0.65} \cdot D^{0.3}} \]  

(3)

\( K_{an} \) – the coefficient, considering the actual service period of the pipeline analog to a wear of its walls on 1 mm in certain operation conditions; the values \( K_{an} \) determined by results of statistical data processing of industrialverse by a wear of the operated pulp pipelines at pipes from soft steel, are chosen on [15] depending on a transported material type (\( K_{an} = 0.038 \)); \( n \) – number of working positions of the counted pulp pipeline to the extreme pipe wear; \( \psi \) – a wear coefficient of irregularity on a circle of the counted pulp pipeline; \( k_a \) – coefficient of the relative wear resistance of the used structural material, determined by data [15]; \( k_u \) – relative abrasiveness coefficient of the transported material; \( v_{cp} \) – average traveling speed of a pulp in the pipeline, m/s; \( S_{cp} \) is average percentage by pulp weight, kg/kg; \( D \) – caliber of the pulp pipeline, m.

The specific wear of the pulp pipeline at hydrotransport of a ash pulp is a reciprocal value of T1.

While calculating it is accepted that \( \psi = 2.5 \), and the coefficient of the relative wear resistance for steel pipe material makes 3.1.0, according to recommendations [15]. According to data of the operation and maintenance phase of pulp pipelines of thermal power plant’s hydraulic ash removal systems ashes hydrotransport on pipes is carried out at a speed about 1.2 m/s, solid slag – 1.5 m/s and liquid slag – 1.8 m/s. Weight concentration of hydromix during removal of ashes or ashes and slag composition is 5 … 10% [15].

7. Conclusion Calculations of a specific attrition of pulp pipelines at transportation of ash-slag pulp, by mm/year, containing ashes of neryungrinsky, kuznetsk and the urgalsky coals, are carried out at transportation speeds of 1.2; 1.5 and 1.8 m/s from percentage by pulp weight of 5 and 10%.

The analysis of the received calculation results shows that the most intensive attrition arises at hydrotransport of neryungrinsky coal ashes at a speed of transportation is 1.8 m/s and concentration of a pulp is 10%, in this case the wear of pulp pipelines is up to 2.25 mm/year. It is explained by the increased abrasive properties of neryungrinsky coals ashes in comparison to ashes of kuznetsk and urgalsky coals, caused by bigger fineness of neryungrinsky coal ashes.

The conducted researches show that HTPP-3 pulp pipelines, which have neryungrinsky coal as main fuel, are exposed to an intensive attrition, in this regard the gas measure installation of HTPP-3 pipelines require innovative actions for protection against an attrition for the purpose of increase in work reliability and increase in indexes of operation profitability.

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