TESTING OF GAS PULSE GAS CLEANING SYSTEM OPERATING PARAMETERS OF SURFACES OF POWER AND EXHAUST BOILERS

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Abstract: This article deals with the effective method of cleaning the heating surfaces of power and waste boilers, presents the characteristics of slag-ash and dust entrainment in flue gases, the mechanism of formation and properties of deposits, the description of the scheme and the physical process of pulse cleaning of contaminated surfaces. The results of analytical research of parameters characterizing the operation of the pulse cleaning system and their application to the existing metallurgical complex recovery boiler are covered.

Keywords: power and exhaust boilers, heating surfaces, ash and slag and dust deposits, gas-pulse cleaning, explosive combustion, adhesion, shock wave force, breaking and shear strength, blowing rate.

Introduction.

Power boilers of electric power stations operating on solid fuel, as well as waste heat recovery boilers that utilize the heat of process gases from metallurgical furnaces, as well as characterized by the content in the flue gases of polydisperse entrainment in solid, liquid, and at high temperatures, partly in a vapor state. Ash-and-slag and technological dust in flue gases vary in quantity within wide limits, from 10 to 200 g/m^3 and more and depend on many factors [1, 2, 3]. Interaction of these various, in composition and properties, dust with boiler heating surfaces lead to contamination of the latter, which causes substantial deterioration of operating conditions of heat-using installations, a considerable decrease of their efficiency and productivity.

Main characteristics of ash and slag and process dust.

Factors such as the viscosity of polydisperse entrainment, adhesion conditions at viscosity below critical, mechanisms of their formation for a specific temperature and aerodynamics, determine the process of formation of deposits on surfaces.

The assessment of the self-slagging of boiler surfaces from contaminants or "cleanability" of cleaning devices is based on the calculation of the strength properties of deposits and the characteristics of cleaning systems.

The strength characteristics of dust deposits of some industrial units are given in Table 1.

Table 1. Strength characteristics of dust deposits of industrial aggregates.

Industrial unit name	Shear strength at:				
	dynamic load, Pa			static load, Pa	
	Seal load, kPa				
	250	500	1000	500	1000
Steel Industry Converter	700	1200	2250	4370	6200
Arc furnace	600	1000	1300	2360	2720
Solid fuel steam boiler	250	310	600	730	770

As can be seen from Table 1, according to the auto-geological characteristics, metallurgical dust belongs to the group of firmly sticking, and dust of solid fuel steam boilers - to the group of weak sticking.

Mechanism of deposit formation on heating surfaces

Deposits are divided into two groups - loose and related. If only gravity forces act between dust particles in the sediment, they are classified as friable. Such forces in these sediments are mainly of molecular and electrostatic nature. If the process of formation of sediments is accompanied mainly by chemical reactions of active components, fusible components in the dust flow, they are considered to be related.

It is accepted that the slag rate is proportional to the probability of the particle sticking to the screen, which is calculated by the Walsh capture model:

$$\boldsymbol{P_{sticking} = \frac{m_{delay}}{m_{total}} = min\left[\frac{\mu_{crit}}{\mu}, 1\right]} \quad (1)$$

where $\frac{m_{delay}}{m_{total}}$ is the ratio of the mass of the adhered particles to the total mass; μ is the effective viscosity of the particle; μ_{crit} is the viscosity at the critical point at which the particle is considered to adhere.

The viscosity value of a particle is calculated from the Browning equation:

$$log\left(\frac{\mu}{T-T_S}\right) = \frac{14788}{T-T_S} - 10{,}931 \quad (2)$$

where T is the particle temperature, T_S is the temperature shift.

It is assumed that the viscosity depends only on the temperature and composition of the dust load, while the temperature shift depends on the mineral composition of the dust load [4]:

$$T_S = 306{,}63 \cdot A - 574{,}31 \quad (3)$$

$$A = \frac{3{,}19Si + 0{,}855Al + 1{,}6K}{0{,}93Ca + 1{,}5Fe + 1{,}21Mg + 0{,}69Na + 1{,}35Mn + 1{,}47Ti + 1{,}91S} \quad (4)$$

The temperature value of the outer layer of the dirt can be determined from the expression:

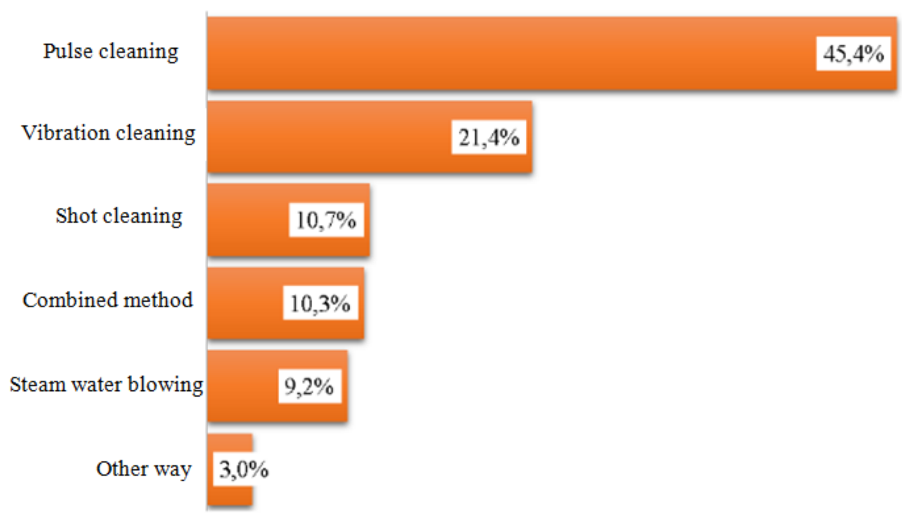
$$T_3 = \frac{T_1 + T_2}{2} + \frac{Kh}{\lambda_3}\left(T_г - \frac{T_1 + T_2}{2}\right) \quad (5)$$

where T_1, T_2 is the water temperature before and after the heating surface, ^{o}C; K is the actual heat transfer coefficient, Вт/m^2·K; $T_г$is the gas temperature at the sampling site, ^{o}C.

Selection of cleaning means for heating surfaces

Prolonged operation of steam and hot water boilers, waste heat boilers and other technological units equipped with various means of cleaning heating surfaces has allowed accumulating rich experience and knowledge in the choice of methods and methods of cleaning heating surfaces. Each method has advantages and disadvantages in terms of efficiency and reliability, which are discussed in detail in the works. [1, 4].

Nowadays, pulse, vibration and shot peeling are the most widespread on power and utilization boilers. Mixed cleaning methods, with rare exceptions, include two or all three of the above-mentioned methods of cleaning of heating surfaces (Pic.1).



Picture 1: Fraction of applications of individual methods for cleaning the heating surfaces of exhaust heat boilers

The mechanism for removal of deposits on the heating surface by gas-pulse cleaning devices

The Gas Pulse Cleaning Unit (GPC) is a moderate intensity pulsed wave generator. Due to the expiration of the impulse chamber, placed outside the gas duct of the boiler, with supersonic speed of combustion products are a complex wave and thermogazdynamic effect on external deposits, heat-exchanging and enclosing surfaces. Explosion (deflagration) combustion of gas-air mixtures in the chambers with the subsequent expiration of the explosion products generates compression waves. The destructive effect of compression waves and the dynamic pressure of the pulse jet of combustion products are removed from the heating surfaces of dust deposits. Besides, the pulsating action of these waves causes vibration on the surfaces, which contributes to further destruction and removal of deposits.

Besides saving energy by improving the aerodynamics of the gas duct and reducing costs by eliminating manual cleaning, the use of GPS allows to significantly improve the efficiency of boiler heating surfaces. Due to the application of GPS, the thermal efficiency of boilers is increased by 1.5-2% [5].

The total effect of direct force on the deposition on the heating surfaces, as well as the associated effects on the equipment, depends on the initial shock energy of the detonation at the outlet of the pulse chamber and the angle of attack on the surface. The initial energy can be considered proportional to the product of the combustible mixture volume in the active part of the PC (pulse camera) per square of the flame propagation velocity at the open end of the PC. The flame propagation velocity depends on the reactivity of the combustible mixture, its composition, temperature and pressure, and the nature of the flow. Wave velocity, having the full force of detonation, can reach about 2200 m/s, the maximum pressure is 20 times higher than the initial one. Such supersonic wave speed can be calculated as the speed of the thermal motion of molecules during combustion of combustible mixture. For example, for stoichiometric ratio in the mixture of hydrogen and oxygen in normal conditions (Ts= 291 K and Ps= 1 atm.), calculated velocity of detonation, its final temperature and pressure will be equal to 2806 m/s, 3583 K and 18,05 atm. respectively. [6, 7].

The intensity of the shock wave on the surfaces, especially in the depth of the tube beam, is not evenly distributed and does not depend on the location of the PC. When shock waves collide with a solid surface, they are reflected and spread in all directions, and in spite of relatively low intensity, these waves penetrate deep into the inter-tube space. In this case, the presence of compression and expansion waves in the deposited material causes a weakening of the binding forces in the deposition.

The compressive impact wave penetrates the deposited material and is reflected from the hard surface (pipe or wall) again as a compressive wave to the free deposition surface, from which it is reflected as a rarefaction wave, etc.

The impact of a shockwave on an open surface is the main, but not the only, effect that causes destruction and removal of deposits. Most of the effect can be attributed to a thermal shock, which causes thermal stress and weakens the adhesion forces between the deposit and the heating surface. Thermal shocks are particularly effective in the boiler's convection bundles, where the flue gas temperature is relatively low (economizers and air heaters). And the speed of gas flows, caused by kinetic energy, additionally contributes to the abrasion of the sediment layer [7].

The formula for determining the operating parameters of the GPS device.

Mathematical description of the combustion process of the gas-air mixture in the pulse chamber is based on the equation of continuity and conservation of the pulse in a basic form in dimensionless parameters:

$$\frac{y_1}{r} - v_1 = \int_0^1 \frac{\rho}{\rho_1} d\eta - 2\int_0^1 \frac{\rho}{\rho_1} f(\eta) d\eta + + \int_0^1 \frac{\rho}{\rho_1} f^2(\eta) d\eta \qquad (6)$$

$$\frac{\rho_2}{\rho_1}\overline{v_1} = \int_0^1 \frac{\rho}{\rho_1} f^2(\eta)d\eta - \int_0^1 \frac{\rho}{\rho_1} f(\eta)d\eta \qquad (7)$$

Where $\frac{y_1-y_2}{r} = \eta$ is a dimensionless coordinate used to describe the velocity profile at the initial section of the jet; v_1, v_2 is the transverse velocity components at the internal and external boundaries of the jet; *r* is the width of the mixing zone; ρ is the density.

To find the value of velocity on the axis of the main stream section, we use the equation of momentum conservation

$$A\bar{v}_m^2 = F_0/F \qquad (8)$$

where

$$A = \int_0^1 \frac{2(1-b\lambda^2)-\bar{v}^2 d\eta}{(1-b\lambda^2)(\bar{v}_m \cdot \bar{v})^2} \qquad (9)$$

$$\bar{v}_m = v_m/v_0 \qquad (10)$$

i.e. represents the ratio of the velocity on the jet axis to the initial velocity of expiration (velocity on the cut of the chamber); F_0, F - the cross-section of the pulse chamber and the jet.

In a spherical shock wave dependence of pressure drop on time is well described by the formula

$$\Delta(p)t = \Delta p\left(1 - e^{t_+/t}\right) \qquad (11)$$

where Δp is the maximum pressure in the wave; *e* is the base of the natural logarithm.

For industrial pulse chambers with a length of 5-20 m the dependence of the pressure drop from the distance to the chamber cut is as follows:

$$\Delta p = 0{,}4\left(\frac{u}{D_Д}\right)^2 E^{2/3}\frac{1}{x^{1,25}}10^5 \qquad (12)$$

where Δp is the pressure peak in the shock wave, Н/м^2; *u* is the velocity of the flame at the outlet of the chamber, м/с; $\left(\frac{u}{D_Д}\right)^2 E$ is the reduced energy of the charge, kJ; D_D is the detonation velocity for the given combustible mixture, м/с.

When the gas flow affects the dust particles in the sediment layer, the autodesynctivity forces F_{adh}, the particle weight *P*, the aerodynamic force F_{force} and the lifting force F_{lif}act. The conditions of particle separation can be expressed as inequality:

$$F_{force} \geq \mu\left(F_{adh} + P + F_{lif}\right) \qquad (13)$$

where μ is the friction coefficient.

The force of aerodynamic influence of the flow is expressed by the formula:

$$F_{force} = C_х\rho S\frac{v^2}{2} \qquad (14)$$

where C_x - particle resistance coefficient; ρ - flow density, кг/м^3; S - obstacle section (heating surface pipes), m^2; v - flow velocity of combustion products, м/с [1].

Analytical research of operating parameters of the GPS device and the results of its practical application in an industrial plant

The analytical research was carried out for the system of GPS surfaces for the recycling boiler (RB)of one of the copper smelting plants, which serves for utilization of the heat of process gases, leaving the furnace with suspended melting.

The aim of the study was:

- to determine the main wave characteristics of pulse combustion and their application in establishing the optimal operating modes of the GPS device;

- to determine the statistical significance of correlation dependencies between wave characteristics and the effects of sediment removal;

- optimize the impulse chamber design and fuel-air mixture consumption to ensure the required wave characteristics and cleaning effects.

The following boundary conditions were adopted for the calculations:

1. Three standard sizes of RB are considered: a) RB -4500-200; b) RB -4500-143; c) RB -4500-120;

2. The concentration of oxygen (O_2) in a fuel oxidizer for the considered RB standard sizes is taken in the following values: a) O_2 - 21 %; b) O_2 - 24 %; c) O_2 - 30 %; d) O_2 - 33 %. The flammable substance is natural gas;

3. Estimated time of filling RB with a combustible mixture - 8÷20 sec;

4. Maximum distance from the cut of RB to the heating surface, where dust deposits accumulate - 10 m (according to the design dimensions of the RB);

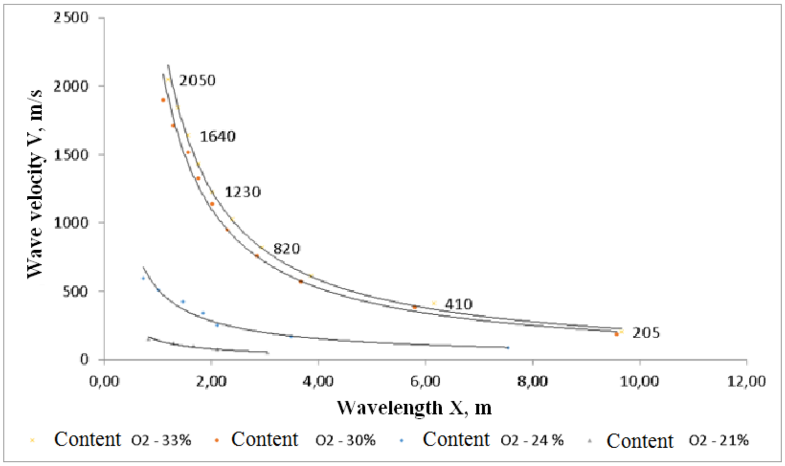
5. Maximum developed shock wave speed depending on the concentration of O_2 in the fuel oxidizer is assumed to be 2200 m/s;

6. The critical blowing rate of the layer of strongly sticking deposits (typical for copper smelting) is assumed to be equal to 180 m/s.

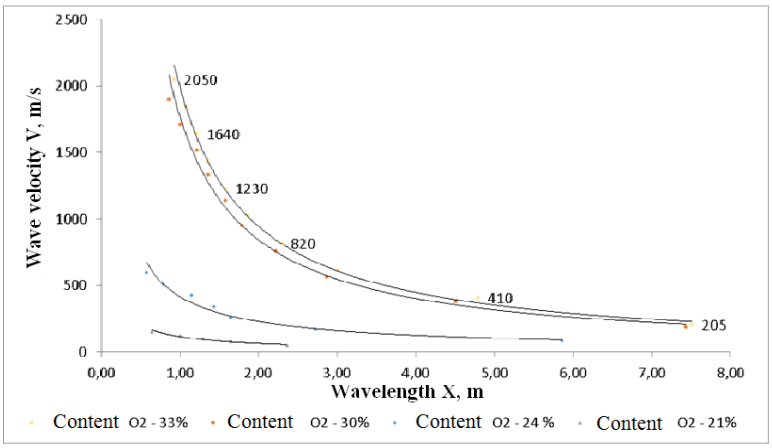
According to the above method, shock propagation velocities of -*V* (m/s) at specific distances from the cut of RB -*X* (m) are calculated.

The approximating curves determining the statistical significance of the correlation dependences of the variables *V* and *X* are constructed on the *V*-*X* diagrams.

Figures 2, 3 and 4 in diagrams *V*-*X* show the dependence curves of two variables V and X for the IR-4500-200, IR-4500-143 and IR-4500-120, respectively.



Picture 2. Correlation dependency curve diagram *V* and *X* variables for the RB -4500-200



Picture 3: Diagram of correlation curves of *V* and *X* variables for RB -4500-143

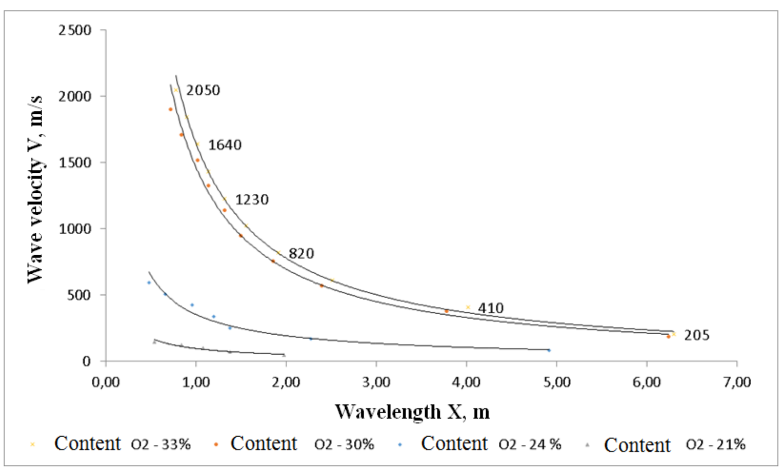


Figure 4: Diagram of correlation curves of *V* and *X* variables for RB -4500-120

Table 2 presents the equations of correlation dependences of *V*-*X* variables at different concentrations of O_2 in an oxidizer. In all cases, the value of approximation reliability is higher than 0.9.

Table 2. The equations of correlation dependences of the variables V-X

O_2 concentration in oxidizer	V-X Dependency equations		
	PC -4500-200	PC -4500-143	PC -4500-120
33%	$V= 1993,7x^{-1,079}$	$V= 1649,9x^{-1,079}$	$V=2617,2x^{-1,079}$
30%	$V= 1772,6x^{-1,072}$	$V= 1468,8x^{-1,072}$	$V=2322,7x^{-1,072}$
24%	$V= 415,15x^{-0,871}$	$V= 356,36x^{-0,871}$	$V=517,07x^{-0,871}$
21%	$V= 113,96x^{-0,861}$	$V= 97,996x^{-0,861}$	$V=141,58x^{-0,861}$

Based on the obtained dependence equations, shock wave velocities at a distance of 10 m from the PC cut were determined for all considered PC standard sizes.

At the concentration of O_2 in the oxidizer 21% and 24%, the shock velocity was much lower than the critical sediment blowing rate.

According to the analysis of the results obtained on the performance characteristics of the pulse chambers, some constructive and technological solutions to improve the system of GPS surfaces of heating the newly engaged recycling boiler (RB) at one of the copper smelting plants of Central Asia were proposed. After the implementation of the corresponding solutions, the analysis of the GPS operation was carried out. The efficiency of the decisions made was assessed by the temperature difference of process gases at the RB outlet before and after the GPS was switched on. Long-term monitoring of technological parameters of RB operation showed a significant temperature difference of gases at the RB outlet after GPS, which varied from 30 to 70 ^{o}C, which ensured the normative mode of RB operation.

Summary and Conclusions.

Based on the analysis of literature sources on the contamination of surfaces of power solid fuel boilers and recovery boilers behind metallurgical furnaces, the mechanisms of dust deposits formation on the surfaces of boilers and criteria that determine the adhesive characteristics of dust deposits have been studied. An algorithm for calculating the working parameters of the GPS as the most effective way to clean the heating surfaces was compiled. Critical speeds of dust deposit blowing, typical for power and utilization boilers, are revealed. The main wave characteristics of pulse combustion are determined. The estimation of the statistical significance of correlation dependences between wave characteristics and the effect of sediment removal is made. Optimization of the pulse chamber design and fuel-air mixture consumption to provide the necessary wave characteristics and cleaning effects on the example of the existing industrial plant is performed.

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