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# METHODS AND MEANS TO IMPROVE THE EFFICIENCY THERMAL PROCESSING OF SOLID FUEL IN A FLUIDIZED BED

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# МЕТОДЫ И СРЕДСТВА ПОВЫШЕНИЯ ЭФФЕКТИВНОСТИ ТЕРМИЧЕСКОЙ ПЕРЕРАБОТКИ ТВЕРДОГО ТОПЛИВА В КИПЯЩЕМ СЛОЕ

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# МЕТОДИ ТА ЗАСОБИ ПІДВИЩЕННЯ ЕФЕКТИВНОСТІ ТЕРМІЧНОЇ ПЕРЕРОБКИ ТВЕРДОГО ПАЛИВА В КИПЛЯЧОМУ ШАРІ

**Abstract.** Problems of improving a fluidized bed technology by way of pulsing air (gas) fed into the bed are considered. A model of and calculation procedure for rational parameters of the coal particles pulsating flowing, moving and firing in the fluidized bed as well as empirical dependence of efficiency of gassing process during combustibles firing in the bed are proposed, which take into account operation parameters of the pulsating fluidized bed. Physics of impact of amplitude-frequency characteristics of the air pulsating feed on the completeness of the coal particles burning-out in the bed was investigated. It is stated that the pulsations period T = 0.5 – 2 s and porosity ψ = 0,3 - 0,4 are rational parameters as they increase rate of solid fuels burning-out in the pulsed fluidized bed by 20 - 40% if compared with stationary bed. Technical facilities (pulsators) were designed, which feed pulsing air into the fluidized bed and provide controllable air stream pulse shapes and pulse ratio.

**Keywords:** fluidized bed, period, pulse ratio, combustion, pulsator.

The global tendency for coal, mining, metallurgical and by-product-coke enterprises consists in their incorporation in common production string that allows optimization of resource sharing, cutting of expenses and engineering output with greater extra cost. For majority of coal enterprises such solution consists in adoption of energotechnological treatment of low-grade coal in fluidized bed.

The significant advantage of this technology is possibility of its realization by reconstruction of existing at every enterprise standard boiler units with minimal capital outlays. The end products of this technology are coal-volatile matter and solid residue with high content of carbon – coke or semicoke. In terms of ecological and economic efficiency there are sufficient reasons for using of coal-volatile matter for gasification or combustion and solid residue as a process fuel with improved use value in comparison with source coal [1].

Advantages of fluidized bed are noted by many researchers and developers, but at the same time this technology has some shortcomings [2]. In particular equalization of temperature and concentration in the bed induced by intensive mixing of solid particles results in decreasing of process motive force.

Sometimes a breakthrough of considerable gas quantity without sufficient contact with solid granular material reduces a base product yield and complicates realization of catalytic processes. In addition when air dynamic pressure is insufficient the slagging of internozzle space and of nozzles of air diffusing fire grates occurs. Elimination of these defects is possible by application of fluidizing agent (gas, air) pulsing flow. Under the control of velocity, frequency and pulse ratio of fluidizing agent jets in reaction space it is possible to obtain different flow structure, to intensify heat mass exchange processes and to raise unit capacity [3].

The main purpose of this work is investigation of pulse regimes in technological processes of fluidized bed for ensuring of equalization of process flow in all volume of bed and for intensification of interphase transition and of chemical reactions.

Let's consider the mathematical model of coal particle combustion under pulsing flow of fluidizing agent (gas, air). In this case so-called "one particle" approach to description of coal particle behaviour in flow. In so doing the trajectory and particle migration velocity are obtained on the ground of analysis of forces actuating a particle of variable mass in pulsing gas suspension flow. On the ground of literature analysis the formulas for main parameters of gas suspension (fractional void volume, density and viscosity) are selected, which allow taking into account transient oscillation of carrying phase (impulse) as well as influence of magnitudes determining bed characteristics, namely inert and coal particle diameters, temperature, gas or air density and viscosity. Combination of these formulas is first applied in terms of one model [4]

$$\frac{d\delta}{dt} = -\frac{4D(c-c_0)}{\beta \nu \rho_s d_0^2 \delta}\left[1+0{,}276\sqrt{\frac{d_0}{\nu_g}\left|U-U_п\right|}\right];\ \frac{dU}{dt} = 2g\,\frac{\rho_s-\rho_ч}{2\rho_ч+\rho_s}+\frac{36\mu_s\left(U-U_п\right)}{d_0^2\delta^2\left(2\rho_ч+\rho_s\right)};\quad (1)$$

where $\delta = d/d_0$ – relative particle diameter; $t$ – time; $D$ – diffusion coefficient; $c_0, c$ – oxygen concentration in flow and on particle surface, respectively; $\beta$ =12/32 – ratio of molecular weights of carbon and oxygen; $\nu$ – stoichiometric coefficient in front of carbon in equation of reaction current on particle surface; $\rho_s$, $\rho_ч$,– density of gas suspension and coal particle, respectively; $d_0$ – initial particle diameter; $\nu_g$ – gas kinematic viscosity; $U$ – particle migration velocity; $U_п$ – pulsating velocity of gas suspension; $\mu_s$ – viscosity of gas suspension.

Set of equations (1) is solved by Runge-Kutt method with initial conditions $\delta$ = 1, $U$ = 0 when $t$ = 0. As a parameter, describing influence of pulsation on particle combustion rate under flow variable parameters the magnitude of relative decline of combustion time

$$\theta = \frac{\Delta t_g}{t_{g_0}} = \frac{t_{g_0} - t_g}{t_{g_0}}$$

where $t_g$, $t_{g0}$ – particle combustion time under pulsing and steady air delivery regimes, respectively. It is obvious that the more is value of $\theta$ the more effective may be considered the regime parameters of pulsing flow. The dependence of relative decline of combustion time on pulse ratio is shown at the fig. 1.

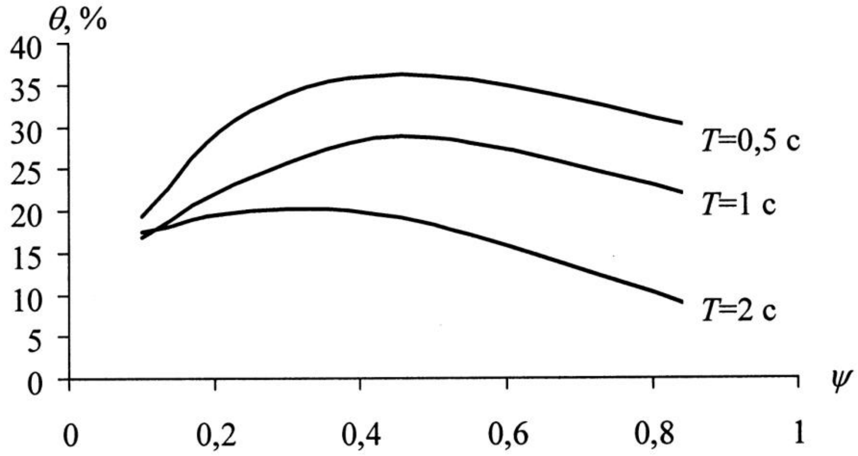



Figure 1 – Relative decline of combustion time of coal particle

Apparently from fig. 1 the influence of pulse ratio change on combustion rate of coal particle may be described as continuous function with maximum, which drifts to the side of lesser pulse ratio when pulsation period increases. The rational parameters of pulsation are period $T$ = 0,5 – 2 s and pulse ratio $\psi$ = 0,3 – 0,4. Under such parameters solid fuel combustion rate in pulsing fluidized bed is 20 – 40 percent up on stationary state.

On the ground of this model the influence of form of air velocity pulsation on the time of coal particle being in the bed compared with gas suspension stationary flow with equal discharge within a period is studied. In the first case the pulsing flow with superposition of polyfrequency component (fig. 2) was used, but in the second case air delivery into the bed was realized by pulse-reversible mode (fig. 3) with pulse delivery of primary air flow to furnace sublattice part and secondary flow over fuel bed.

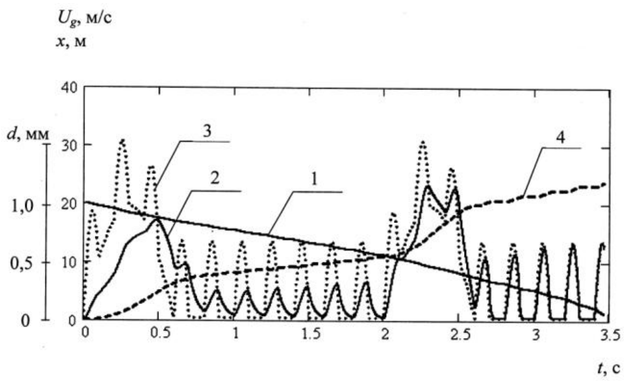
The research showed that maximal disparity in phase velocities of gas suspension composed of inert and coal, which ensures complete combustion of particle in the bed under the influence of pulsing jets, is reached when pulse ratio $\psi$ = 0,3 – 0,4.

Gassing calculation during solid fuel combustion in the fluidized bed is made using calculation procedure [5]. The specificity of pulsing regime namely dependence on process time requires calculation of average integrated over pulsation period data values. This complicates analysis when investigating according to this calculation procedure. We first have obtained the empirical dependence, which allows qualitative analysis of efficiency of fuel combustion in the bed when changing different parameters of both gas suspension bed and pulsing air flow

$$\phi(z) = A[1 - \exp(-Bz)]; \qquad (2)$$

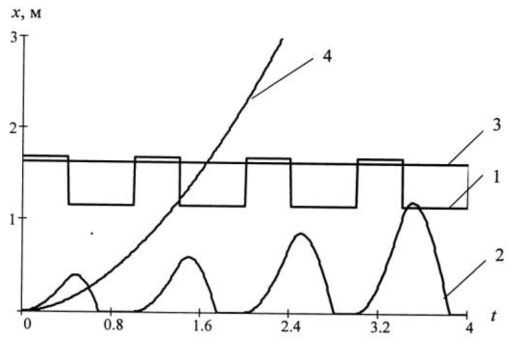
$$A = 0{,}64\left(\frac{H_0}{d_i}\right)^{0.1}\left(\frac{k_1}{k_2}\right)^{-0.09} Pe^{-0.15}\psi^{-0.05};\ B = 966{,}85\left(\frac{H_0}{d_i}\right)^{0.1}\left(\frac{k_1}{k_2}\right)^{-0.1} Pe^{-0.65}\psi^{-0.15}.$$

where $z$ – relative mass concentration of combustibles in the bed; $H_0$ – initial bed height; $d_i$ – inert particle diameter; $k_1$, $k_2$ – reaction rate constants; $Pe$ – Péclet number; $\psi$ – flow pulse ratio.




1 – particle diameter; 2 – particle velocity; 3 – gas velocity; 4 – particle track

Figure 2 – Process parameters in polyfrequency pulsing flow




1, 2 – pulse-reversible; 3, 4 – stationary air delivery into the bed

Figure 3 – Bed height and particle coordinate in the fluidized bed

The dependence of function of solid fuel combustion in gas suspension (2) on relative mass concentration of combustibles in the bed under pulsing air delivery is described by complicated linear function in regard to exponent with negative argument. Its coefficients are inversely proportional to Péclet number, pulsation pulse ratio as well as to chemical reactions rate constants ratio and ratio of such parameters of gas suspension as initial bed height and inert particle diameter.

The results of comparison of calculated data for stationary and pulsing flows are shown at the fig. 4, 5.

Apparently from fig. 4 that pulsing air delivery results in essential growth of content of carbon oxides in the gas as well as in fuel combustion rate increase i.e. in increase of nondimensional combustion function (fig. 5). The research showed that use of pulsing air delivery when concentration of combustibles in the bed $z$ = 0,04÷ 0,01 results in rising of efficiency of gassing processes by 20 % – 50 %.

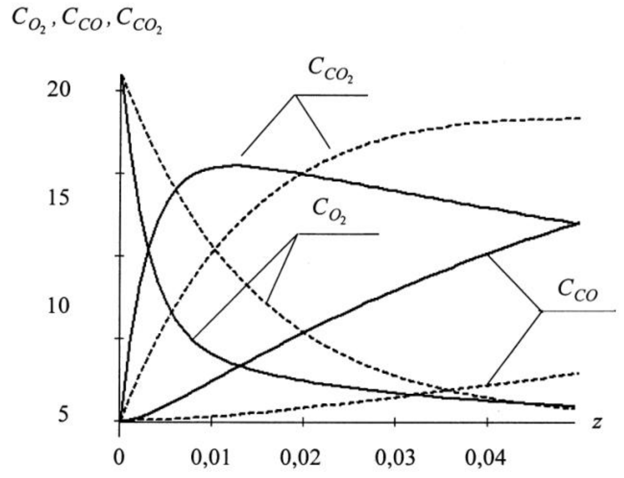



Figure 4 – Change of combustion products composition

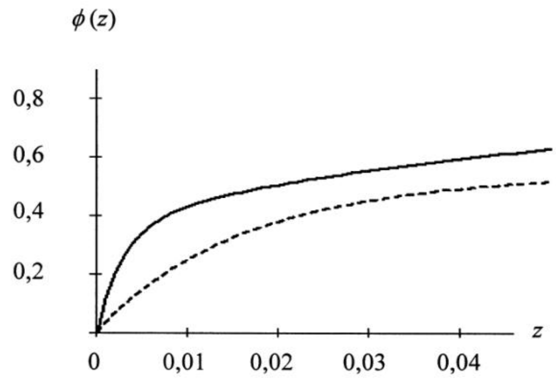



Figure 5 – Change of combustion function $\phi(z)$

Pulsing air delivery is realized by pulsator. The analysis of techniques for pulsing air flow delivery showed that well known constructions don't allow regulation of pulse ratio of air impulses and differ by constructional and technological complexity as well as by high air drag [6]. Specialists of IGTM of NAS of Ukraine have elaborated constructions of such types of pulsators: pulsator with trilobite impeller [7] (fig. 6), pulsator with slit rotor [8] (fig.7), disc pulsator [9] (fig. 8), which allow regulation of flow pulse ratio and form of pulsation.

The scientific basis of calculation of parameters of processes in the fluidized bed under pulsing air delivery into the bed first are suggested. For realization of theoretical backgrounds the different constructions of pulsators are elaborated. The research showed that rational control of parameters of organized carrying agent pulsation results in more uniform passing of processes along cross-section and height of the fluidized bed, in raising of heat transfer efficiency both as a result of influence on kinetics of coal particles reactions and owing to improvement of bed aerodynamics, to liquidation of dead space and gas localized movement.

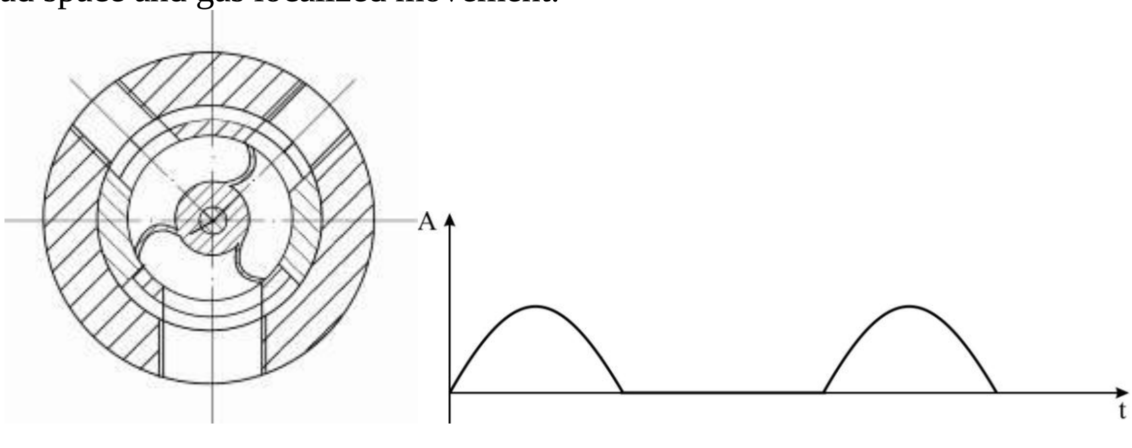



Figure 6 – Pulsator with trilobite impeller

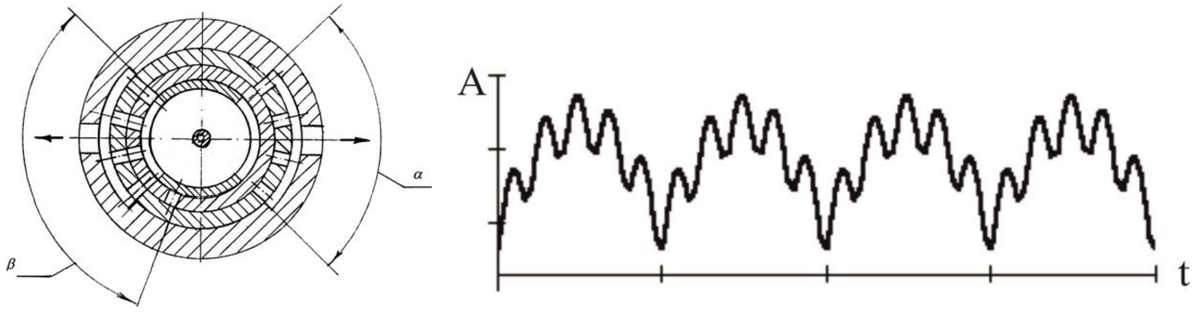



Figure 7 - Pulsator with slit rotor

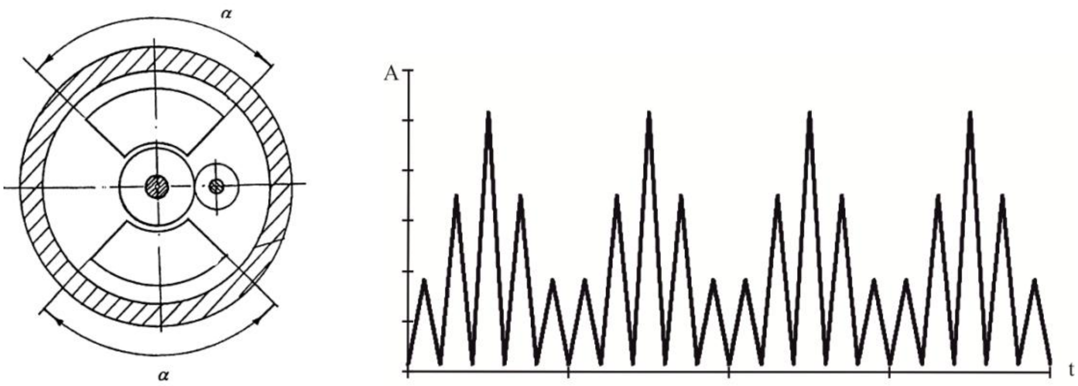



Figure 8 – Disc pulsator

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**Анотація**. Розглянуто питання удосконалення технології киплячого шару за допомогою організації пульсуючої подачі повітря (газу) в шар. Запропоновано модель і методику розрахунку раціональних параметрів пульсуючого потоку, руху і горіння вугільної частинки в киплячому шарі, а також емпіричну залежність ефективності процесу газоутворення при вигорянні горючих в шарі , що враховує режимні параметри пульсуючого киплячого шару. Проведено дослідження закономірностей впливу амплітудно-частотних характеристик пульсуючої подачі повітря на повноту вигоряння вугільних частинок в шарі. Визначено, що раціональними параметрами пульсацій є період Т = 0,5 - 2 с і шпаруватість $\psi$ = 0,3 - 0,4, що забезпечує підвищення швидкості горіння твердого палива в пульсуючому киплячому шарі порівняно зі стаціонарним на 20 - 40%. Розроблено конструкції технічних засобів (пульсаторів), в яких реалізується пульсуюча подача повітря в киплячий шар.

**Ключові слова:** киплячий шар, період, шпаруватість, горіння, пульсатор.

**Аннотация.** Рассмотрены вопросы усовершенствования технологии кипящего слоя посредством организации пульсирующей подачи воздуха (газа) в слой. Предложены модель и методика расчета рациональных параметров пульсирующего потока, а также движения и горения угольной частицы в кипящем слое. Предложена эмпирическая зависимость эффективности процесса газообразования при выгорании горючих, учитывающая режимные параметры пульсирующего кипящего слоя. Проведены исследования закономерностей влияния амплитудно-частотных характеристик пульсирующей подачи воздуха на полноту выгорания угольных частиц в слое. Определено, что рациональными параметрами пульсаций являются период $T$ = 0,5 – 2 с и скважность $\psi$ = 0,3 – 0,4, что обеспечивает повышение скорости горения твердого топлива в пульсирующем кипящем слое по сравнению со стационарным на 20 – 40 %. Разработаны конструкции технических средств (пульсаторов), реализующих подачу пульсирующего воздуха в кипящий слой и обеспечивающих регулирование формы колебаний, а также скважности воздушного потока.

**Ключевые слова.** Кипящий слой, период, скважность, горение, пульсатор.

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