

INVESTIGATION OF THE BEHAVIOR OF MERCURY COMPOUNDS IN COAL COMBUSTION PRODUCTS

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The main mechanisms of transformation of mercury compounds in coal combustion products in the region of high temperatures have been analyzed. A kinetic model of the process of gas-phase oxidation of metal mercury vapors is proposed. The features of the behavior of the investigated compounds in systems of cleaning combustion products from harmful impurities have been considered.

Mercury compounds are among the most toxic and long-lived microimpurities in the atmospheric air. Native sources of mercury emitted into the atmosphere are water surfaces, soils, plants, forest fires, volcanos, etc. and, according to the estimates of different authors, the total emission of mercury is about 3000 tons/year [1]. Among the anthropogenic sources of mercury compounds are industries, heat power engineering, and incineration of rubbish. The anthropogenic emission of mercury in Europe is about 600 tons/year. In the countries of Eastern Europe (including the European part of Russia), the release of mercury compounds into the atmosphere is mainly due to the operation of solid-fuel thermal power plants [2].

Unlike the majority of metals forming small impurities in solid fuel, mercury is an extremely volatile element. Therefore, mercury compounds are present in solid-fuel combustion products before their release into the atmosphere practically completely in the gas phase. The further behavior of these toxic components of flue gases is determined by the processes of their photochemical oxidation in cloud drops and precipitation on the earth's surface near the emission source [3].

The dominant forms of mercury in solid-fuel combustion products are vapors of metal mercury Hg^0 , as well as compounds of bivalent mercury Hg(II) : $\text{HgCl}_2(\text{g})$ and $\text{HgO}(\text{g}, \text{s})$ [4]. As the results of thermodynamic calculations show, the redistribution of mercury between different compounds varies over wide ranges and depends on the regime parameters of the process (initial fuel composition, temperature, pressure, etc.) [5, 6].

Because of the poor solubility of metal mercury vapors in water, removal of Hg^0 from combustion products is only possible upon its chemical conversion into readily soluble compounds of Hg(II) . In the present paper, the main mechanisms of Hg^0 - Hg(II) conversion have been analyzed, a kinetic model of the process is proposed, and the features of the behavior of mercury compounds in systems of removing harmful impurities from solid-fuel combustion products have been considered.

Thermodynamic Analysis of the Process. The content of mercury in power-generating coals varies from 0.01 to 1 mg/kg [7]. In the process of fuel combustion, mercury goes to the gas phase in the form Hg^0 . At an average content of this impurity in the initial fuel of 0.1 mg/kg, the Hg^0 concentration in combustion products is about $15 \mu\text{g}/\text{nm}^3$.

The processes of further conversion of Hg^0 are rather complicated and consist of homogeneous and heterogeneous reactions of the gaseous components containing Hg and Cl atoms [8]. Among the methods of mathematical modeling of such processes, an important role is played by the methods of thermodynamic analysis permitting qualitative estimation of the efficiency of mercury redistribution between the gaseous and condensed phases under various conditions of the process.

In the present paper, for thermodynamic analysis of the process of mercury conversion in solid-fuel combustion products, we chose coals widely differing in the content of Hg and Cl: Kuznetsk coal (lean, underground mining, $\text{Hg} = 0.06 \text{ mg/kg}$, $\text{Cl} = 0.5 \text{ g/kg}$), Pechersk coal (Vorkutaugol', $\text{Hg} = 0.06 \text{ mg/kg}$, $\text{Cl} = 1.0 \text{ g/kg}$ and near-Moscow

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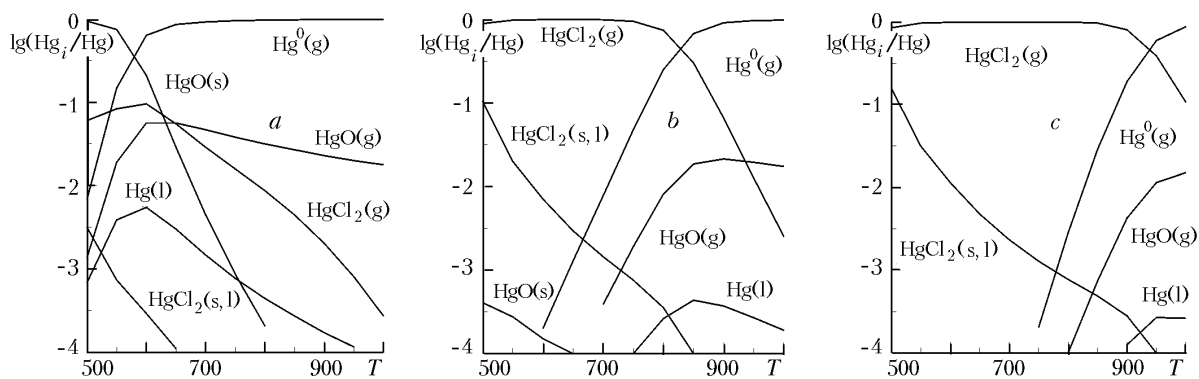


Fig. 1. Equilibrium distribution of mercury between components in combustion products of Kuznetsk (a), Pechersk (b), and near-Moscow (c) coals depending on the process temperature ($\alpha = 1, 2, p = 0.1$ MPa). T , K.

coal (basin-average, Hg = 0.6 mg/kg, Cl = 5.0 g/kg) [7]. The initial composition of the Kuznetsk coal on a working-mass basis was taken to be as follows (%): W = 1.8, A = 19.64, C = 70.31, H = 2.99, O = 3.06, S = 0.47, and N = 1.73. The composition of the mineral part: SiO₂ = 55.4, Al₂O₃ = 25.4, Fe₂O₃ = 7.2, CaO = 4.6, MgO = 1.9, K₂O = 1.9, Na₂O = 0.7, TiO₂ = 1.0, P₂O₅ = 1.6, and MnO = 0.3. For the Pechersk coal the respective composition is equal to (%): W = 2.5, A = 31.2, C = 55.69, H = 3.45, O = 4.44, S = 1.13, and N = 1.59. The composition of the mineral part: SiO₂ = 62.6, Al₂O₃ = 19.4, Fe₂O₃ = 8.6, CaO = 3.0, MgO = 2.3, K₂O = 2.1, and Na₂O = 1.0. For the near-Moscow coal (%): W = 7.5, A = 41.63, C = 33.07, H = 2.65, O = 11.09, S = 3.50, and N = 0.56. The composition of the mineral part is: SiO₂ = 48.2, Al₂O₃ = 35.6, Fe₂O₃ = 9.6, CaO = 4.1, MgO = 0.7, K₂O = 0.7, Na₂O = 0.3, and TiO₂ = 0.8 [9].

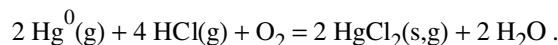
Calculations were performed by the TETRAN complex [10]. To describe the prevalent chemical elements of the coal working mass (including Cl), we used the thermodynamic model of [11], taking into account 275 chemical components, of which 123 components were condensed. The model was extended by including the chemical element Hg, forming a microimpurity in the coal working mass. In so doing, we added to the set of components of the chemically reactive system Hg⁰(g, l), HgO(g, l, s), HgCl₂(g, l, s), and HgS(s). The calculations were performed in the two-phase approximation, where all condensed substances are represented in the form of a solution that is in equilibrium with perfect gas.

During burning of solid fuel in combustion chambers of power plants, coal particles burn in the air atmosphere, and the excess air factor thereby (ratio of the quantity of air used to its stoichiometric quantity for a given coal) is an important regime parameter of the process. Under real conditions, $\alpha > 1$, i.e., the process of formation of toxic compounds proceeds in an oxidizing medium, although local values of α , as the process proceeds, can be less than unity. Therefore, in calculating the equilibrium composition of the chemically reactive coal/air system we took the value of $\alpha = 1.2$, which is typical of the conditions of direct burning of coal.

The results of the calculation of the equilibrium distribution of mercury between different components depending on the process temperature in combustion products of the investigated coals are given in Fig. 1, where Hg is the total quantity of mercury in the system and Hg_i is the quantity of mercury in individual components. Analysis of Fig. 1 shows that at a small concentration of Cl in the chemically reactive system (combustion products of Kuznetsk coal) the main Hg-containing component is Hg⁰(g), which at low temperatures oxidizes to oxide HgO(g) with its subsequent condensation (Fig. 1a). As the Cl content in the coal is increased to 1 g/kg (Pechersk coal), the dominating role at low temperatures is played by the reaction of HgO(g) with the main chlorine-containing component of combustion products HCl with the formation of chloride HgCl₂(g) (Fig. 1b). Gas-phase mercury chloride is highly soluble in water and can be removed from the gas in systems of wet cleaning of combustion products from sulfur oxides. As the chlorine concentration is further increased, the point of equality of the concentrations of Hg⁰(g) and HgCl₂(g) shifts to the region of higher temperatures and with a chlorine concentration of 5 g/kg in the initial fuel reaches 950 K, which agrees with the results of the thermodynamic analysis of the composition of products of incineration of solid domestic garbage containing a large amount of chlorine [12].

Kinetic Features of the Process. The mechanism of gas-phase oxidation of metal mercury vapors in solid-fuel combustion products is still not clearly understood. As was shown in [13], at high temperatures $\text{Hg}^0(\text{g})$ reacts fairly rapidly with HCl , Cl_2 , and O_2 , less rapidly with NO_2 , and practically does not interact with NH_3 , N_2O , SO_2 , and H_2S . The heterogeneous oxidation of $\text{Hg}^0(\text{g})$ in volatile ash particles in the presence of NO_2 , HCl , and SO_2 can also play an important role in the process of Hg^0 conversion into $\text{Hg}(\text{II})$ [14].

The main process of oxidation of metal mercury vapors in coal combustion products is their interaction with HCl in the presence of O_2 [4]. The global kinetic scheme of the process can be represented in the form



At low temperatures ($T \leq 750$ K) equilibrium shifts towards the formation of HgCl_2 , and at high temperatures HgCl_2 reacts with H_2O to form oxide HgO , which then decomposes into Hg^0 and O . As the measurement data of [13] show, the behavior of the chemical components in the Hg-HCl-O_2 system is determined by the concentration of HCl . At small values of this quantity ($x_{\text{HCl}} \leq 0.01$ vol.%), the Hg oxidation rate strongly depends on x_{HCl} . An increase in the HCl content in the gas leads to a change in the limiting stage of the process, and the Hg^0 oxidation rate no longer depends on x_{HCl} .

At the present time, there is no satisfactory description of the process dynamics. The existing kinetic models [15, 16] are rather conditional and do not permit taking into account the main features of the proceeding of the reaction. Let us make use of the experimental data of [13] to restore the kinetic parameters of the gas-phase $\text{Hg}^0\text{-HgCl}_2$ conversion. Under the conditions being considered, the reaction of interaction of Hg^0 with HCl and O_2 can be given in the form of three elementary stages:



Since, in the system under investigation, water vapors are absent, the concentrations of OH radicals and H atoms are small and the last two reactions proceed only in the forward direction. The concentration of O atoms is determined by the content of molecular oxygen in the system and can be calculated from the chemical equilibrium at a given temperature [17]:

$$\frac{n_{\text{O}_2}}{n_{\text{O}}} = 2.7 \cdot 10^{-13} \exp\left(\frac{29\,820}{T}\right) n_{\text{O}_2}^{1/2} .$$

The system of kinetic equations describing the change in the Hg^0 and HgO concentrations is of the form

$$dn_{\text{Hg}^0}/dt = -k_{f1}n_{\text{Hg}^0}n_{\text{O}_2} + k_{b1}n_{\text{HgO}}n_{\text{O}} ,$$

$$dn_{\text{HgO}}/dt = k_{f1}n_{\text{Hg}^0}n_{\text{O}_2} - k_{b1}n_{\text{HgO}}n_{\text{O}} - k_{f2}n_{\text{HgO}}n_{\text{HCl}} .$$

At a quasi-stationary Hg^0 concentration the change in the HgO concentration in the course of the process is described by the expression

$$n_{\text{Hg}} = (n_{\text{Hg}})_0 \exp(-t/\tau) , \quad (4)$$

$$\tau = \left(\frac{k_{b1}}{k_{b2}} \frac{n_{\text{O}}}{n_{\text{HCl}}} + 1 \right) / (k_{f1}n_{\text{O}_2}) .$$

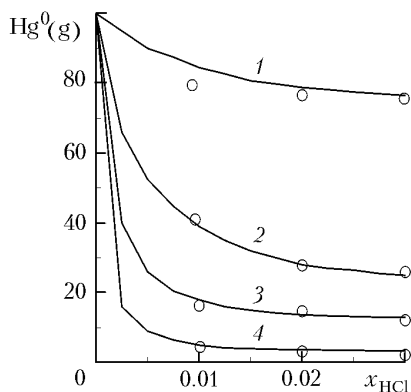


Fig. 2. Behavior of the Hg^0 concentration in the $\text{Hg}^0\text{-HCl-O}_2$ system depending on the HCl content: 1) $T = 573$; 2) 773; 3) 973; 4) 1173 K. Dots, experimental data [13]. $\text{Hg}^0(\text{g})$, $\mu\text{g}/\text{m}^3$; x_{HCl} , vol.%.

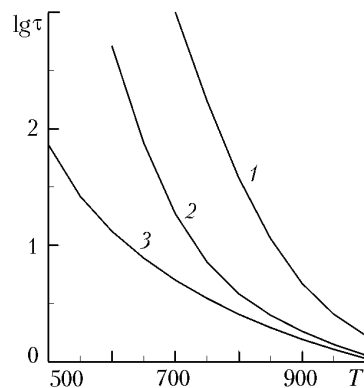


Fig. 3. Characteristic time of $\text{Hg}^0\text{-HgCl}_2$ conversion in combustion products of Kuznetsk (1), Pechersk (2), and near-Moscow (3) coals. τ , sec; T , K.

Relation (4) was used to determine the kinetic parameters of the process by adjusting the calculated curves to the experimental data of [13]. Figure 2 shows the behavior of the Hg^0 concentration depending on the HCl content at various temperatures of the process. The calculated data were obtained for a rate constant $k_{f1} = 3.1 \cdot 10^{-6} \exp(-4300/T) \text{ cm}^3/\text{sec}$ and a ratio $k_{b1}/k_{f2} = 2.3 \cdot 10^{-9} \exp(33,300/T)$. The process time was varied from 0.7 sec at the temperature $T = 1173$ to 2.6 sec at $T = 573$ K [13]. The molar fraction of oxygen in the system was equal to 0.1. As is seen from Fig. 2, in the 600–1200 K temperature range the proposed kinetics model fairly well describes the measurement data.

Let us estimate with the aid of the obtained relations the characteristic time of $\text{Hg}^0\text{-HgCl}_2$ conversion in combustion products of the above-considered coals. Since, under real conditions, the concentration of water vapors in the system is large and the reaction proceeds in both the forward and backward direction, the kinetic equation of the process can be written as

$$dn_{\text{Hg}}/dt = -[n_{\text{Hg}} - (n_{\text{Hg}})_{\text{eq}}]/\tau.$$

Figure 3 gives the dependence of the τ value on the process temperature calculated by formula (4). The concentrations of the components entering into this formula were taken from the data of the thermodynamic calculation. It is seen that with decreasing temperature, as the combustion products pass through the heat exchangers of the power plant, the Hg^0 oxidation time increases. In the near-Moscow coal combustion products, the value of this quantity throughout the temperature range does not exceed 1 min. On the other hand, as the results of the thermodynamic analysis show, in the Kuznetsk coal combustion products $\text{Hg}^0(\text{g})$ is a prevalent component up to a temperature of the order of 600 K (see Fig. 1a), at which the value of τ is equal to about 10^5 sec.

It should be noted that the equilibrium concentration of HCl used in the calculation strongly depends on the temperature. In particular, in the Pechersk coal combustion products x_{HCl} decreases from 10^{-4} at a temperature of 1000 K to 10^{-5} at 700 K. This is a consequence of the fact that at low temperatures the great bulk of chlorine is bound into solid chlorides of alkali metals. The data on the formation kinetics of the ash part of the solid-fuel combustion products are limited [18] and do not permit estimating the behavior of all condensed components of the chemically reactive system. Nevertheless, it may be assumed that the heterogeneous reaction rate in the Cl-K-Na system is lower than the respective quantity for the considered gas-phase process. This makes it possible to correct the obtained estimates towards a decrease in the Hg^0 oxidation time and an increase in the HgCl_2 content.

The results of the analysis performed show that a fairly rapid oxidation of Hg^0 in the Kuznetsk coal combustion products is only possible in the region of temperatures above 800 K, where the equilibrium concentration of HgCl_2 is lower than the respective concentration of Hg^0 . Therefore, the great bulk of Hg for the given coal is released

into the atmosphere in the form of metal mercury vapors. The conditions favoring the conversion of Hg^0 into HgCl_2 are realized only for solid fuels with a large content of chlorine (salty coals [19, 20] and solid garbage [12, 21]).

Mercury Compounds in Cleaning Systems. Among the systems of cleaning solid-fuel combustion products are, first of all, the electrostatic filters removing up to 98% of volatile ash [22] and the wet lime desulfurizers reducing the SO_2 emission into the atmosphere by an order of magnitude [23]. The electrostatic filters also retain fairly effectively bivalent mercury compounds condensed and adsorbed on ash particles, and the wet desulfurizers bind the great bulk of gaseous HgCl_2 (up to 70%) [24]. Metal mercury vapors upon gas cooling partially condense [16] and can interact with the main gas desulfurization product $\text{CaSO}_4(\text{s})$ to form $\text{HgSO}_4(\text{s})$ [24]. Nevertheless, the great bulk of $\text{Hg}^0(\text{g})$ passes through the cleaning system and is released into the environment.

Electrostatic filters are the most widely used kind of gas cleaners of coal-dust power plants. Along with volatile ash they collect condensed mercury compounds: $\text{Hg}^0(\text{l})$, $\text{HgO}(\text{l}, \text{s})$, $\text{HgCl}_2(\text{l}, \text{s})$, and $\text{HgS}(\text{s})$, as well as gas-phase components adsorbed on ash particles [25]. Let us estimate the efficiency of trapping $\text{HgCl}_2(\text{g})$ by ash particles in the high-temperature range.

The adsorption process can be considered as a pseudoreaction between $\text{HgCl}_2(\text{g})$ and the "active centers" on the particle surface [26]. The kinetic equation describing the change in the concentration y of adsorbed HgCl_2 is written in the form

$$\frac{dy}{dt} = k_a (y_{\max} - y) \rho_{\text{HgCl}_2} - k_d y. \quad (5)$$

As a result of the processing of the experimental data in the temperature range $T = 400\text{--}600$ K, in [26] the following values of the parameters entering into Eq. (5) were obtained: $k_a = 3.54 \cdot 10^6 \exp(-956/T) \text{ cm}^3/(\text{g} \cdot \text{sec})$, $k_d = 1.07 \cdot 10^{-2} \exp(-1255/T) \text{ 1/sec}$, and $y_{\max} = 2.0 \cdot 10^{-3} \text{--} 2.3 \cdot 10^{-6} T$ (g HgCl_2/g ash). The results of the thermodynamic calculation of the equilibrium composition of the near-Moscow coal combustion products give, at $T = 600$ K, values of the ash and HgCl_2 concentration equal to $1.4 \cdot 10^{-5}$ and $8.3 \cdot 10^{-11} \text{ g/cm}^3$, respectively. Integration of Eq. (5) at these values of the concentrations shows that in the time $t = 10$ sec the value of y decreases by about 6%. Thus, no marked absorption of $\text{HgCl}_2(\text{g})$ by ash particles before they get into the filter zone is observed.

The method of wet lime desulfurization of gas is based on the interaction of SO_2 with the lime solution circulating in the absorption tower-scrubber [23]. As a result of the interaction, insoluble calcium sulfite semihydrate and gypsum are formed. These are removed from the system by means of settlers and filters. To estimate the efficiency of binding of gas-phase HgCl_2 by a lime solution, consider the liquid-phase chemical reactions in the $\text{SO}_2\text{--HCl--HgCl}_2\text{--Ca(OH)}_2$ system. Under gas-liquid quasi-equilibrium conditions, the conversion of bivalent mercury compounds Hg(II) forming stable complexes with ions OH^- , Cl^- , and SO_3^{2-} can be described with the use of the corresponding equilibrium constants [27, 28]. In the solution, SO_4^{2-} ions resulting from the SO_3^{2-} oxidation by molecular oxygen are also present. Nevertheless, because of the high value of the corresponding equilibrium constant the concentration of HgSO_4 is insignificant [27]. The main form of the existence of Ca in a saturated solution of calcium hydroxide is Ca^{2+} ions [29]. The equilibrium concentration of Ca(OH)_2 in the solution at $T = 298$ K is equal to 1.48 g/dm^3 , which yields a concentration of $[\text{OH}^-] = 0.04 \text{ mole/dm}^3$ and a pH value = 12.6.

During the formation of insoluble salts of Ca, adsorption of Hg(II) by solid particles occurs. Under the conditions of reversibility of the process, the concentration of $[\text{Hg(II)}]_a$ is determined by means of the K_a absorption coefficient [30]. The balance equation for Hg(II) in this case can be written in the form

$$(p_{\text{Hg}})_0 = p_{\text{Hg}} + \rho R T L \left(\sum_i [\text{Hg(II)}]_i + [\text{Hg(II)}]_a \right). \quad (6)$$

Since, under the considered conditions, the concentration of $[\text{Hg(II)}]_a$ is determined in terms of the $[\text{Hg(II)}]$ concentration by the relation $[\text{Hg(II)}]_a = K_a [\text{Hg(II)}][\text{Ca}]_s \mu_s$, (6) can be rewritten in the form

$$(p_{\text{Hg}})_0 = p_{\text{Hg}} \left\{ 1 + \rho R T L H_{\text{HgCl}_2} \sum_i [\text{Hg(II)}]_i / [\text{HgCl}_2] (1 + K_a [\text{Ca}]_s \mu_s) \right\}.$$

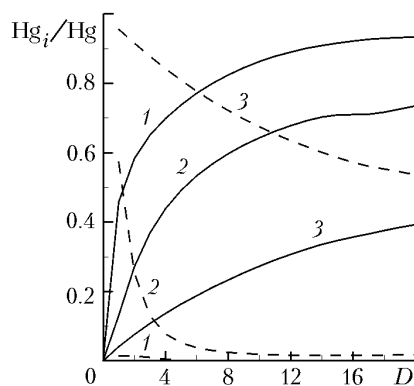
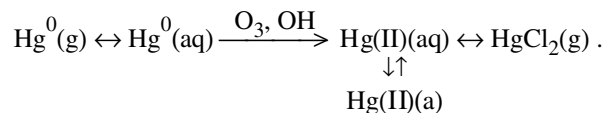


Fig. 4. Mercury distribution between components: Hg(II)(a) (solid curves) and Hg-HgCl₂(g) (dashed curves) upon radiation-chemical conversion of Hg⁰(g) depending on the irradiation dose: 1) T = 343; 2) 353; 3) 363 K. D, J/g.

The calculation of the Hg(II) distribution between different forms performed using the above relations and the values of the parameters entering into them [$[H_{\text{HgCl}_2}] = 14 \text{ moles}/(\text{dm}^3 \cdot \text{Pa})$ [27], $K_a = 200 \text{ dm}^3/\text{g}$ [30], $[\text{Ca}]_s = 0.02 \text{ mole}/\text{dm}^3$ [29], $L = 10^{-4} \text{ dm}^3/\text{g}$] shows that practically the whole quantity of [Hg(II)] is in the adsorbed state. As is seen from the experiments on the desorption of Hg(II) compounds from solid particles [30], an appreciable part of adsorbed mercury undergoes further chemical conversion into compounds HgO and HgS, which are insoluble under the usual temperatures. It should also be noted that, as a consequence of the small value of the equilibrium constants for the reactions $\text{HgO}(\text{s}) + \text{H}_2\text{O} = \text{Hg}^{2+} + 2\text{OH}^-$ and $\text{Hg}(\text{OH})_2(\text{s}) = \text{Hg}^{2+} + 2\text{OH}^-$ ($3.63 \cdot 10^{-26}$ and $1.10 \cdot 10^{-25} \text{ (mole}/\text{dm}^3)^2$ respectively) [27], part of the Hg(II) under the conditions being considered can precipitate in the form of HgO and Hg(OH)₂. Thus, the results of the estimation made show that, under the conditions of wet lime desulfurization of the gas, a considerable quantity of HgCl₂ can be removed from the system.

The *electron-beam treatment of gas* is one of the most promising methods of cleaning waste gases of solid-fuel power plants from nitrogen and sulfur oxides [31, 32]. The method is based on the obtaining in the gas, under the action of radiation, of small amounts of active components (atoms and radicals). The active components react with nitrogen and sulfur oxide, transforming them into substances trapped by the filters. This process proceeds most effectively at temperatures of the order of 340 K and includes both the gas-phase and the liquid-phase chemical reactions [33].

The existing mathematical models of the physicochemical processes proceeding in the gas under the action of radiation [34] permit estimating the efficiency of the given method of cleaning as applied to the removal of metal mercury vapors from the gas. The kinetic model of radiation-chemical conversion of Hg⁰(g) proposed in [35] consists of liquid-phase oxidation of the given microimpurity by O₃ molecules and OH radicals in Hg(II) followed by the adsorption of oxidation products by soot particles in the solution:



Soot particles result from the combustible loss of the initial fuel and are removed from the gas flow by means of filters. The formation of O₃ molecules and OH radicals occurs under the action of radiation on the gas macrocomponents (N₂, O₂, CO₂, and H₂O). The liquid phase (finely dispersed aerosol particles) is formed in the process of volume condensation of water and sulfuric acid vapors. Sulfuric acid vapors result from the gas-phase oxidation of SO₂ induced by the radiation action on the gas.

In the present paper, the kinetic model of [35] has been used to calculate the process of conversion of metal mercury vapors into adsorbed compounds Hg(II)(a) and HgCl₂(g) under the action of radiation. As a working medium, we chose the Kuznetsk coal combustion products, in which, as the results of the thermodynamic analysis show, Hg⁰(g) is the prevalent component up to a temperature of the order of 600 K (see Fig. 1a). Cooling of com-

bustion products down to a process temperature close to optimum is achieved by injecting into the system a proper quantity of water. The initial composition of the chemically reactive system before the irradiation zone is as follows: $N_2 = 70$, $CO_2 = 14$, $H_2O = 12$, $O_2 = 4$, $SO_2 = 0.1$, $NO = 0.03$, $NH_3 = 0.23$, $HCl = 2.2 \cdot 10^{-3}$, and $Hg^0(g) = 10^{-7}$ vol.%.

Figure 4 shows the change in the concentrations of $Hg(II)(a)$ and $HgCl_2(g)$ upon the radiation-chemical conversion of $Hg^0(g)$ depending on the irradiation dose D and the process temperature T . It is seen that with increasing D and decreasing T the $Hg(II)(a)$ concentration increases and the concentration of $HgCl_2(g)$ decreases in the system. Mercury compounds adsorbed by soot particles are fairly effectively trapped by electrostatic filters. Gas-phase mercury chloride that is biologically more active than $Hg^0(g)$ [1] is practically completely released into the environment. At a temperature and an irradiation dose close to the optimum values for the process under consideration ($T \cong 340$ K, $D \cong 20$ J/g), the degree of conversion of $Hg^0(g)$ into $Hg(II)(a)$ reaches 93%, and the concentration of $HgCl_2(g)$ is practically equal to zero. The degree of conversion of SO_2 and NO into compounds trapped by filters is equal to 89 and 73%, respectively. Because of the small concentration of Hg compounds in the gas, the chemical processes involving them proceed without additional expenditure of energy.

CONCLUSIONS

1. The results of the thermodynamic calculation of the equilibrium distribution of mercury between different components depending on the process temperature in combustion products of different coals show that at a Cl concentration in the coal of less than 0.5 g/kg (Kuznetsk coal) the main Hg-containing component is $Hg^0(g)$, which at low temperatures oxidizes to oxide $HgO(g)$ with its subsequent condensation. As the content of Cl is increased to 1 g/kg and more (Pechersk and near-Moscow coal), the dominant role at low temperatures is played by $HgCl_2(g)$, which is highly soluble in water and can be removed from the gas in the system of wet cleaning of combustion products from sulfur oxide.

2. The kinetic parameters of the process of gas-phase conversion of Hg^0 into $HgCl_2$ in the 600–1200-K temperature range have been determined by adjusting the calculated curves to the experimental data. Using the obtained expressions for the rate constants of the elementary stages of the process, the characteristic time of $Hg^0(g)$ oxidation in combustion products of the above coals has been estimated.

3. Features of the behavior of mercury compounds in the systems for cleaning combustion products of coals from harmful impurities have been considered. It has been shown that no marked absorption of $HgCl_2(g)$ by ash particles before they get into the zone of electrostatic filters is observed. The efficiency of binding gas-phase $HgCl_2$ by a lime solution has been estimated. It may be concluded that, under the conditions of wet lime desulfurization of the gas, a considerable amount of $HgCl_2(g)$ can be removed from the system. It has been shown that electron-beam cleaning of combustion products of coals from harmful impurities decreases the concentration of $Hg^0(g)$ by more than an order of magnitude.

NOTATION

A , ash content of coal, mass %; a , adsorbed component; aq , component in aqueous solution; $[A_i]$, component A_i concentration in aqueous solution, mole/dm³; D , irradiation dose, J/g; g , gas-phase component; H_i , Henry constant of components, mole/(dm³·Pa); k , rate constant of elementary reaction, cm³/sec; K_a , constant of adsorption, dm³/g; k_a , adsorption rate constant, cm³/(g·sec); k_d , desorption rate constant, 1/sec; L , liquid-phase volume in a mass unit of gas, dm³/g; l , liquid-phase component; n_i , numerical densities of components, cm⁻³; p , pressure, Pa; p_i , partial pressures of components, Pa; pH, solution acidity; $R = 8.31 \cdot 10^6$, universal gas constant, cm³·Pa/(mole·K); s , solid-phase component; t , time, sec; T , temperature, K; W , coal moisture, mass %; x_i , molar fractions of components; y , concentration of adsorbed $HgCl_2$, g/g of ash; α , air excess factor; μ , molar weight, g/mole; ρ , gas density, g/cm³; ρ_i , partial densities of components, g/cm³; τ , characteristic time of the process, sec. Subscripts: 0, initial value; 1, 2, reaction number; a, adsorption; b, backward direction; d, desorption; eq, equilibrium value; f, forward direction; i , component number; max, maximum value; s, solid phase.

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