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NUMERICAL MODELING OF ORTHOSILICIC ACID NUCLEATION IN THE HYDROTHERMAL SOLUTIONS AT DIFFERENT TEMPERATURES AND PH

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Key words: hydrothermal solution, orthosilicic acid, nucleation, sizes of colloidal particles.

ABSTRACT

Nucleation of orthosilicic acid with formation of colloidal silica particles in hydrothermal solutions was studied by the method of numerical simulation. Numerical simulation was done at different parameters: chemical composition, temperatures, pH, ionic strengths of hydrothermal solutions. The rates of nuclei formation and its growth, time dependence of orthosilicic acid concentration, final sizes of colloidal silica particles were calculated. Results of calculations were compared with experimental data. Experiments were carried out with solutions of Mutnovskoye and Pauzhetskoye geothermal fields. The approach based on numerical simulation can be used for developing of technology of silica extraction from hydrothermal solutions.

INTRODUCTION

There is a problem to study physical and chemical characteristics of colloidal silica in hydrothermal heat carrier in the context of silica extraction technology and increasing of effectiveness of heat carrier using (Potapov V.V., Karpov G.A., Podverbny V.M., 2002; Potapov V.V., 2003).

Colloidal silica forms in the hydrothermal solution during several stages (Potapov V.V., 2003). Silica comes into the solution as molecules of silicic acid as a result of water chemical interaction with silica-alumina rocks of hydrothermal fields at the depth 1.0-3.5 km in thermal anomaly zones under a high temperature (up to 250-350^{0}C) and pressure (4.0-20 MPascal). Hydrothermal solution is multicomponent. Compounds with Na, K, Si, Ca, Mg, Al, Fe, Cl, S, C, B, Li, As, Cu, Zn, Ag, Au and others are present at the solution as ions and molecules.

Under the temperature 250-350^{0}C when solution contacts with rocks minerals a total silica content C_t (mole/kg) in water can be estimated by α-quartz solubility(Crerar D.A., 1971):

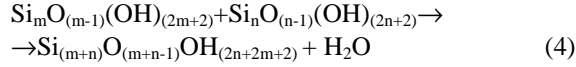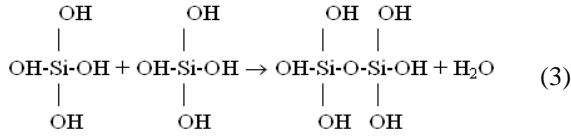$$\lg C_t = -1{,}468 + 252{,}9/T - 3{,}217 \cdot 10^5/T^2 \qquad (1)$$

Equation (1) gives the following values of quartz solubility SiO$_2$ (mg/kg): 25^{0}C – 3.46, 50^{0}C – 10.29, 100^{0}C – 47.6, 200^{0}C – 256.0, 250^{0}C – 415.6, 300^{0}C – 592.5. Over rising filtration in fractured-and-porous rocks or during solution movement through the producing wells of geothermal electric power plants (GeoPP) pressure and temperature of the solution reduce and solution is divided in steam and liquid phases. Total silica content C_t in a liquid phase can reach 700-1500 mg/kg. Consequently water solution becomes supersaturated relative to a solubility of amorphous silica C_e (Marshall W.L., 1980). In accordance with experimental data (Marshall W.L., 1980) C_e value (mole/kg) for pure water depends on an absolute temperature T in the following way:

$$\lg C_e = -0.1185 - 1.126 \cdot 10^3/T + 2.3305 \cdot 10^5/T^2 - 3.6784 \cdot 10^7/T^3 \qquad (2)$$

Under the temperature 200^{0}C solubility C_e is 940.8 mg/kg, under the temperature 150^{0}C – 651.8 mg/kg, 100^{0}C – 405.3 mg/kg, 25^{0}C – 130.8 mg/kg.

Such condition of monomeric silicic acid in water solution is unstable. Solution supersaturation S_m which is equal to the difference (C_s-C_e) of orthosilicic acid concentration C_s and solubility C_e causes nucleation and polymerization of silicic acid molecules with condensation of silanol groups and formation of siloxane linkes and partial dehydration

in accordance with the following reactions (Iler R., 1982):

$$\begin{array}{ccccc}
OH & OH & & OH & OH \\
| & | & & | & | \\
OH \cdot Si \cdot OH & + OH \cdot Si \cdot OH & \rightarrow & OH \cdot Si \cdot O \cdot Si \cdot OH & + H_2O \\
| & | & & | & | \\
OH & OH & & OH & OH
\end{array} \quad (3)$$

$$Si_mO_{(m-1)}(OH)_{(2m+2)} + Si_nO_{(n-1)}(OH)_{(2n+2)} \rightarrow$$
$$\rightarrow Si_{(m+n)}O_{(m+n-1)}OH_{(2n+2m+2)} + H_2O \quad (4)$$

CHEMICAL COMPOSITION OF HYDROTHERMAL SOLUTION

Table 1. Ions and cations concentrations in hydrothermal separate from the pipe-line of reverse pumping of Verkhne-Mutnovskaya GeoPP, ionic strength $I_s = 14.218$ mmole/kg, conductivity $\sigma = 1250$ microS/sm, n/d means that concentration was not determined, (-) means that values were not estimated.

Component	mg/l	mg·equ/l	
		mg·equ/l	%mg·equ/l
Na^+	239.4	10.413	88.044
K^+	42.0	1.074	9.080
Ca^{2+}	1.6	0.0798	0.6747
Mg^{2+}	0.72	0.0592	0.5005
$Fe^{2,3+}$	<0.1	<0.0053	0.0448
Al^{3+}	0.27	0.033	0.2790
NH_4^+	1.1	0.0609	0.5149
Li^+	0.71	0.102	0.8624
Cations sum	285.9	11.827	100.0
Cl^-	198.5	5.591	47.664
HCO_3^-	81.0	1.327	11.312
CO_3^{2-}	19.9	0.663	5.652
SO_4^{2-}	192.1	3.9995	34.096
HS^-	4.95	0.15	
H_2S^0	5.92	-	-
F^-	n/d	n/d	-
Anions sum	496.5	11.73	100.0
H_3BO_3	106.9	-	
$(H_4SiO_4)_t$	1190	-	
$(H_4SiO_4)_s$	222	-	
Mineralization M_h, mg/kg	1638.9		
pH	9.35		

It is necessary to study the process of orthosilicic acid nucleation to work out the technology of extraction of silica-containing materials with given characteristics from the hydrothermal heat carrier. Final concentration and the size of colloidal particles before their extraction from aqueous solution depend on the parameters of the process nucleation of orthosilicic acid. Numerical simulation in different conditions corresponding to the heat carrier

characteristics of Verkhne-Mutnovsky GeoPP was made to study the process of nucleation.

Table 1 presents physical and chemical characteristics of liquid phase of hydrothermal heat carrier (separate) of GeoPP. This phase is separated from two-phase water-steam flow in separators of GeoPP. Aqueous solution of separate refers to natrium-potassium-chloride-sulphate type of thermal waters. Total silica content in solution varies in the range of 500-1000 mg/kg, pH=8.0-9.4, ionic strength $I_s = 0.01-0.02$ mole/kg.

MATHEMATICAL MODEL

Mathematical model (Weres 0., Yee A., Tsao L., 1981) worked out by Veres, Yee and Tsao in Lawrence Berkeley Laboratory (USA) was used for numerical simulation. Supersaturation $S_N(T)$ which is equal to C_s/C_e and pH are main factors defining nucleation rate I_N of silicic acid in aqueous solution:

$$I_N = Q_{LP} \cdot Z \cdot (R_{md} \cdot A_{cr} \cdot N_A \cdot M_{Si}^{-1}) \cdot exp(-\Delta F_{cr}/k_B \cdot T) \quad (5)$$

where ΔF_{cr} is a free energy change connected with nuclei formation of critical radius R_{cr}, A_{cr} is the surface area of critical nuclei, $A_{cr}=4 \cdot \pi \cdot R_{cr}^2$, σ_{sw} is the surface tension on silica-water boundary, R_{md} is the rate of molecular precipitation of SiO_2 onto a solid surface, g·$(sm^2 \cdot min)^{-1}$, k_B is Boltzmann constant, M_{Si} is the molar mass SiO_2, N_A is Avogadro constant, Q_{LP} is Lothe-Paund factor, $Q_{LP} = 3,34 \cdot 10^{25}$ kg^{-1}, Z is Zeldovich factor, n_{cr} is the quantity of molecules of SiO_2 in nuclei of critical size.

Critical radius, quantity of molecules in nuclei of critical radius, free energy and Zeldovich factor were estimated in accordance with the following formulas (Weres 0., Yee A., Tsao L., 1981):

$$R_{cr} = 2 \cdot \sigma_{sw} \cdot M_{Si}/(\rho \cdot N_A \cdot k_B \cdot T \cdot lnS_N) \quad (6)$$

$$n_{cr} = (4 \cdot \pi/3) \cdot (\rho \cdot N_A/M_{Si}) \cdot R_{cr}^3 \quad (7)$$

$$\Delta F_{cr} = \sigma_{sw} \cdot A_{cr}/3 = (16 \cdot \pi/3) \cdot \sigma_{sw}^3 (M_{Si}/\rho \cdot N_A \cdot k_B \cdot T \cdot lnS_N)^2 \quad (8)$$

$$Z = [-(\partial^2 \Delta F_{cr}/\partial n_{cr}^2)/(2 \cdot \pi \cdot k_B \cdot T)]^{0.5} =$$
$$(2/3) \cdot [3 \cdot M_{Si}/(4 \cdot \pi \cdot \rho \cdot N_A \cdot n_{cr}^2)]^{1/3} \cdot (\sigma_{sw}/k_B \cdot T)^{0.5} \quad (9)$$

ρ is the density of amorphous silica.

The dependence of the function R_{md} of the rate of SiO_2 molecules deposition on the temperature and pH solution in a given model is shown in the following equations (Weres 0., Yee A., Tsao L., 1981):

$$R_{md} = F(pH, pH_{nom}) \cdot k_{OH}(T) \cdot ff(S_a) \cdot (1 - S_N^{-1}) \quad (10)$$

$$lg\ k_{OH}(T) = 3.1171 - 4296.6/T \tag{11}$$

$$f_f = S_a^5,\ S_a < S_t \tag{12-1}$$

$$f_f = S_t^5 + 5 \cdot S_t^4 \cdot (S_a - S_t),\ S_a > S_t \tag{12-2}$$

$$lg\ S_t = 0.0977 + 75.84/T \tag{12-3}$$

$$F(pH, pH_{nom}) = h_f \cdot f'(pH) + (1-h_f) \cdot f'(pH_{nom}) \tag{13-1}$$

$$f'(pH_{nom}) = f(pH_{nom})/f(7.0) \tag{13-2}$$

$$lg\ f = pH - pK_i + lg[Na^+] \tag{13-3}$$

The dependence of surface tension on the temperature and pH coefficient σ_{SW} is given by the function $I(pH, pH_{nom})$:

$$\sigma_{sw} = H_\sigma - T \cdot S_\sigma - 2.302 \cdot 10^{-3} \cdot n_o \cdot k_B \cdot T \cdot I(pH, pH_{nom}) \tag{14-1}$$

$$I(pH, pH_{nom}) = 0.119 \int_{-\infty}^{pH} F(pH', pH_{nom}(pH')) dpH' \tag{14-2}$$

where $S_a = (1-\alpha_i) \cdot S_N$, α_i is a fraction of silicic acid in ionic form, $pH_{nom} = pH + lg([Na^+]/0.069)$, $[Na^+]$ is an ion activity $[Na^+]$, mole/kg, $pK_i = 6.4$, $f(7.0) = 0.119$, $h_f = 0.45$, H_σ, S_σ are specific enthalpy and entropy of silica surface in water, $H_\sigma = 63.68 \cdot 10^{-3}$ Joule/m^2, $S_\sigma = 0.049 \cdot 10^{-3}$ Joule/m^2·K, $n_o = 6.84$ nm^{-2}.

Equation (5) shows maximum rate I_N of nucleation for the particles with the radius that is higher then critical. Its molecules quantity of SiO_2 is equal to n = $n_{cr}+0.5/Z$. $I_N(t)$ value reaches to maximum in induction time τ_{in} that is necessary to grow and form stable population of the particles which sizes are close to critical. Time dependence $I_N(t)$ has got the form (Weres 0., Yee A., Tsao L., 1981):

$$I_N(t) = I_N \cdot (1-e^{-t/\tau in}) \tag{15}$$

To calculate time τ_{in} the following formula is used:

$$\tau_{in} = 1.08 \cdot 10^{-6} \cdot (6R_{md})^{-1} \cdot (Q_{LP} \cdot Z \cdot R_{cr}^2 \cdot exp(-\Delta F_{cr}/k_B \cdot T))^{-0.25} \tag{16}$$

PROGRAM FOR NUMERICAL SIMULATION
The system of equations (1), (2), (5)-(16) was used to develop MSANUC.FOR program. The solution algorithm in accordance with MSANUC.FOR was the following:

1) Initial values entry: temperature T, pH, concentration of ions and ionic strength of solution, the assignment of total silica C_t content of initial time "TIME" and time step DT, the assignment of initial radii R(I) and particles quantity MP(I) of every class "I" which are present in the solution before nucleation.

2) The calculation of colloidal silica content in solution by summation of particles of all classes:

$$M_{col} = \sum_{I=1}^{I=N} \frac{4 \cdot \pi \cdot \rho \cdot R^3(I) \cdot MP(I)}{3} \tag{17}$$

3) The calculation of concentration of monomeric orthosilicic acid as difference between total content and colloidal silica content:

$$C_s = C_t - M_{col} \tag{18}$$

4) The calculation of current value of supersaturation solution S_N:

$$S_N = C_s/C_e(T) \tag{19}$$

5) The calculation of values of σ_{sw}, R_{md}, R_{cr}, Z, τ_{in}, $I_N(t)$ corresponding to current values S_N, pH and T by equations (5)-(16).

6) The calculation of the quantity of new particles appearing during the time DT in accordance with current value of nucleation rate I_N on a given program step and educing a new class of particles N+1:

$$MP(N+1) = I_N \cdot DT \tag{20}$$

7) The calculation of summary concentration of particles:

$$CONP = \sum_{I+1}^{I=N+1} MP(I) \tag{21}$$

8) The calculation of particle mass difference DPM of every class during the time DT in accordance with the equation:

$$DPM(I) = 4 \cdot \pi \cdot R^2(I) \cdot R_{md} \cdot DT$$

9) The calculation of particle radius R(I) corresponding to a new value of particle mass in every class:

$$R(I) = (R^3(I) + 3 \cdot DPM(I)/4 \cdot \pi \cdot \rho)^{1/3} \tag{22}$$

And the calculation of mean values of R_{cp}, R_{cp}^2, R_{cp}^3 in all classes of particles:

$$R_{cp} = \sum_{I=1}^{I=N+1} \frac{R(I) \cdot MP(I)}{CONP} \tag{23}$$

$$R^2{}_{cp} = \sum_{I=1}^{I=N+1} \frac{R^2(I) \cdot MP(I)}{CONP} \qquad (24)$$

$$R^3{}_{cp} = \sum_{I+1}^{I=N+1} \frac{R^3(I) \cdot MP(I)}{CONP} \qquad (25)$$

10) The calculation of new temperature values, pH, ionic strength of solution if these values change with time. After the tenth step we must return to the second step of the program to make the next cycle. Registration of calculations results in a separate file is provided for: mean radius, summary concentration of particles and concentration of monosilicic acid for given time station.

RESULTS

Table 2 a,b presents the results of numerical simulation of nucleation with MSANUC.FOR program under different temperatures and pH solution. During the initial time colloidal silica content supposed to be zero and all silica was in a monomeric orthosilicic acid form:

$$C_s(t=0) = C_t$$

Simultaneous results show that critical radius R_{cr} increases due to supersaturation reduce when temperature becomes higher. Consequently the tendency for decrease of nucleation rate I_N and increase of induction time τ_{in} takes place; it leads to reduce of particles concentration N_p and increase of final mean radius of the particles R_f. Under the temperature $120\text{-}150^0C$ and higher nucleation hasn't time to develop during a real residence time of hydrothermal solution in wells and thermal equipment of GeoPP.

After nucleation and polymerization completion a part of silica continues to be as molecules of orthosilicic acid H_4SiO_4 which concentration is close to solubility of C_e. It is in equilibrium with colloidal silica. Small amount of silicic acids ions ($H_3SiO_4^-$, $H_2SiO_4^{2-}$, $HSiO_3^-$, etc.) and macromolecules of polysilicic acids are in the solution parallel with colloidal particles and molecules of silicic acids. Data processing obtained by Rozbaum and Rode (Rothbaum H.P., Rohde A.G., 1979) has showed the concentrations of dimmers C_{dimer} and trimers C_{trimer} of silicic acid are approximated by the equations (mole/kg):

$$lgC_{dimer} = -2.10 - 775/T \qquad (26\text{-}1)$$

$$lgC_{trimer} = -3.22 - 919/T \qquad (26\text{-}2)$$

The dependence of constants of orthosilicic acid ionization of the first $K_1 = [H^+]\cdot[H_3SiO_4^-]/[H_4SiO_4]$ and second $K_2 = [H^+]\cdot[H_2SiO_4^{2-}]/[H_3SiO_4^-]$ stages on the temperature has the following form:

$$lgK_1 = -2549/T - 15.36\cdot10^{-6}\cdot T^2 \qquad (27\text{-}1)$$

$$lgK_2 = 5.37 - 3320/T - 20\cdot10^{-3}\cdot T \qquad (27\text{-}2)$$

In accordance with equations (26-1, 26-2) under the temperature $20\text{-}180^0C$ and pH=7.0-9.2 a fraction (portion) of dimmers with respect to orthosilicic acid which concentration is close to a solubility of $C_e(T)$ doesn't exceed 1.0%, a fraction(portion) of trimers is 0.1%, a fraction(portion) of tetramers and low-molecular circular polymers (up to 6 units SiO_2) (Rothbaum H.P., Rohde A.G., 1979) is < 0.1%. A fraction (portion) of ions $H_3SiO_4^-$ and $H_2SiO_4^{2-}$ under such conditions is not more than 14.0%.

The calculations by the method of photon correlation spectroscopy show that particles mean radius of polymerized silica in hydrothermal solution has values from 7.0 up to 30.0 nm, values of particles radii vary from 1.0 up to 50.0 nm (Potapov V.V., 2003).

With the help of MSANUC.FOR final mean size of silica particles under different constant temperatures 20^0C, 40^0C, 50^0C, 60^0C, 80^0C, 100^0C and different constants pH=4-8.5 were estimated. Table 2 presents estimated final mean sizes of the particles (nm).

Table 2. Final mean sizes of silica particles under a constant temperature and different pH; C_S=700 mg/kg; (-) means that it was not estimated.

pH	t, ^{0}C					
	20	40	50	60	80	100
4	5.289	19.247	48.067	156.551	6342.132	-
5	5.290	19.054	47.305	153.158	5858.727	-
6	2.983	16.823	40.691	128.018	4684.754	-
7	2.978	7.667	15.282	38.175	701.463	-
8	0.988	1.219	1.508	1.775	3.488	18.77
8,5	0.645	0.731	0.784	0.841	1.013	1.268

When pH=5-6 and the temperature is 50^0C the calculations were made with step by pH 0.1. It made the possibility to study the influence of pH solution on the size of silica particles more detailed. The estimated results are shown in table 3 and on figure 1.

Table 3. Final mean sizes of silica particles under the temperature 50^0C and different pH; C_S=700 mg/kg.

pH	R_A, nm	pH	R_A, nm
5	47.305	5.5	45.423
5.1	46.995	5.6	44.854
5.2	46.771	5.7	44.007
5.3	46.42	5.8	43.077
5.4	45.954	5.9	42.028

On figure 2 the dependence of concentration of dissolved silicic acid C_S (mg/kg) on time T_p (min) is shown for t=50^0C, initial concentration C_S=700 mg/kg and different values pH; figure 3 presents the dependence of supersaturation S_N on time T_p (min); figure 4 (a-f) presents the dependence of distribution of final sizes of silica particles.

The influence of initial solution concentration C_S (mg/kg) on a final mean size of silica particles (nm) is shown in table 4 and figure 5. Calculations were made under different solution temperatures: 20^0C, 40^0C, 60^0C, 80^0C, 90^0C; different initial solution concentrations C_S (mg/kg): 500, 600, 700, 800, 1000.

Table 4. Values of final mean size of silica particles (nm) under different temperatures t and initial concentrations of solution C_S, pH=8; (-) - means that it was not estimated.

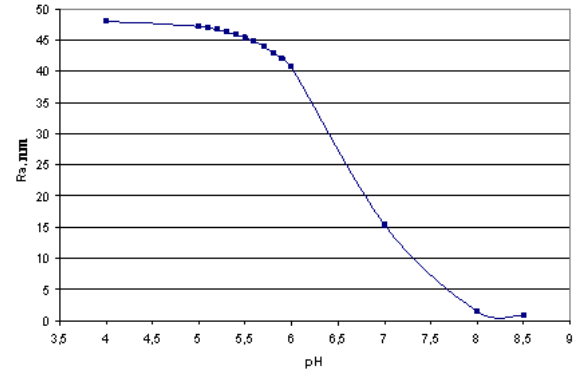| C_S, mg/kg	t, ^0C			
	20	40	50	60
300	93.57	-	-	-
350	12.46	1019.9	-	-
400	4.35	49.11	586.3	-
500	1.79	4.088	8.968	32.71
600	1.246	1.846	-	3.808
700	0.988	1.219	-	1.775
800	0.876	1.054	-	1.311
1000	0.739	0.836	-	0.952
C_S, mg/kg	t, ^0C			
	70	80	85	90
300	-	-	-	-
350	-	-	-	-
400	-	-	-	-
500	-	-	-	-
600	7.56	24.14	56.14	169.8
700	-	3.488	-	6.496
800	-	1.815	-	2.308
1000	-	1.108	-	1.212

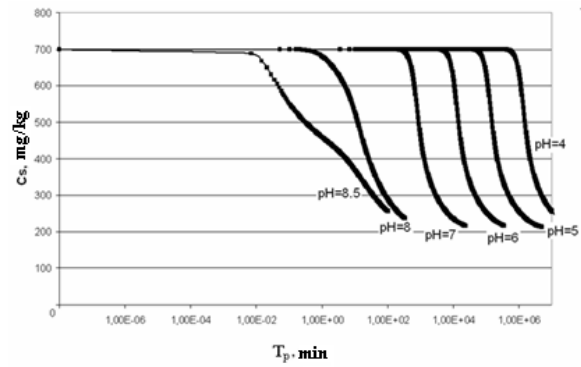Fig. 1. The dependence of final mean size of silica particles on pH. t=50^0C, C_S = 700 mg/kg.

Fig. 2. The dependence of concentration of dissolved silicic acid on time. t=50^0C, initial concentration C_S=700 mg/kg.

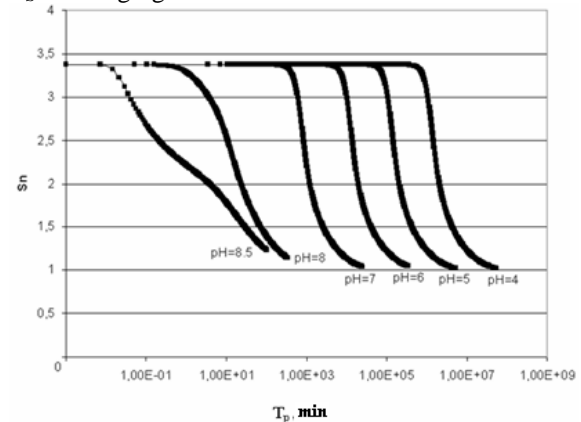Fig. 3. The dependence of supersaturation S_N on time. t=50^0C, initial concentration C_S=700 mg/kg.

a b

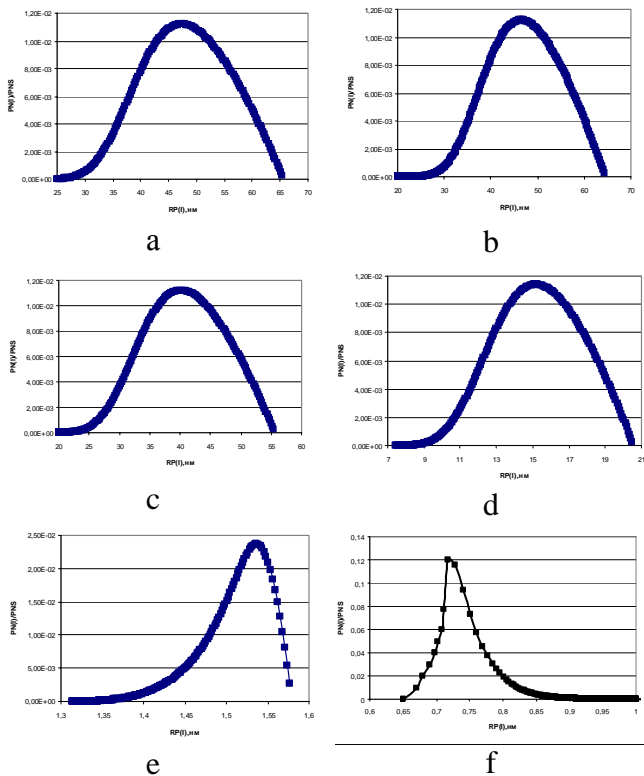c d

e f

Fig. 4. The distribution of particles sizes under the temperature t=50^{0}C, initial concentration C_S=700 mg/kg. a – pH=4; b – pH=5; c – pH=6; d – pH=7; e – pH=8; f – pH=8.5.
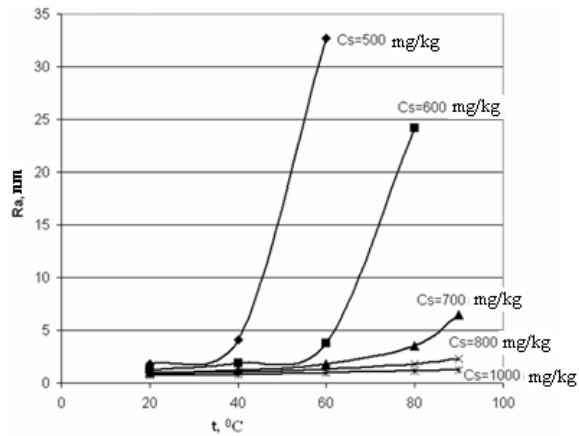

Fig. 5. The dependence of a final mean size of silica particles on different temperatures t and different initial concentrations of the solution C_S; pH=8.

Figure 2 shows that curves reflecting the dependence of concentration of dissolved silicic acid on time have two areas: convex curve reflects homogeneous nucleation, id est the stage of formation of new particles centres, concave part reflects heterogeneous nucleation, i.e. the growth of centres formed earlier.

Figure 6 (a–c) presents the dependence of quantity of the formed particles PNS (nucl) on time T_P (min) and dependence of nucleation rate R_{nuc} (nucl/kg*s) on time T_P (min) under the temperature t=50^{0}C, initial concentration C_S=700 mg/kg and different pH.

On figure 4 left curve part of particles sizes distribution is concave and right curve part is convex.

Figure 7 presents the dependence of concentration of dissolved silicic acid C_S (mg/kg) on time T_P (min) for t=60^{0}C, pH=8 and different initial; figure 8 shows the dependence of supersaturation S_N on time T_P (min); figure 9 (a-e) presents the dependence of distribution of final sizes of silica particles.

It was obtained the following final mean sizes of silica particles (nm) for initial concentration C_S=300, 350 mg/kg, pH=8 and ionic strength corresponding to the solution characteristics of Pauzhetsky deposit (table 5).

Table 5. Values of final mean size of silica particles (nm) under different temperatures t and different initial solution concentration C_S. (-) - means that it was not estimated.

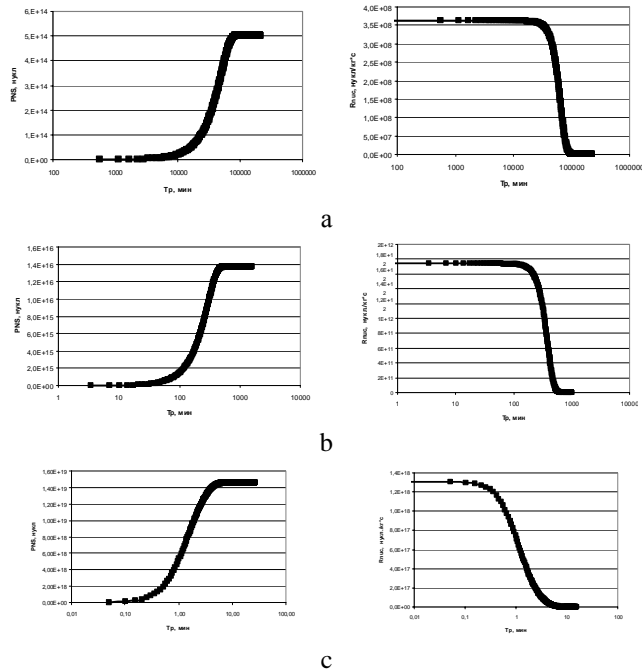| C_S, mg/kg	t, ^{0}C			
	20	30	40	50
300	13.99	129.9	9095.69	-
350	3.59	10.26	63.95	2103.6

a

b

c

Fig. 6. Dependences of formed particles quantity PNS on time T_P and dependences nucleation rate R_{nuc} on time T_P; t=50^{0}C, initial concentration C_S=700 mg/kg. a – pH=5; b – pH=7; c – pH=8.
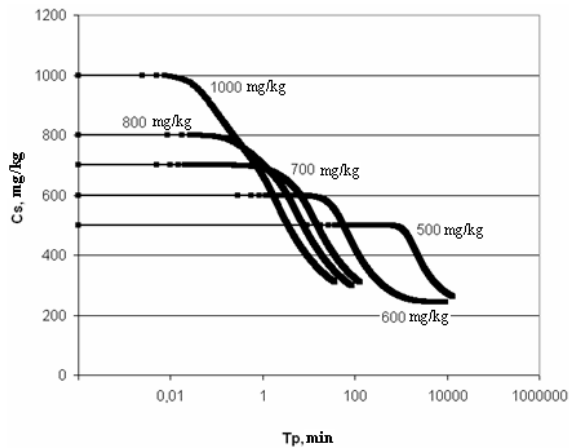
Fig. 7. The dependence of dissolved silicic acid concentration on time. $t=60^0C$, pH=8.
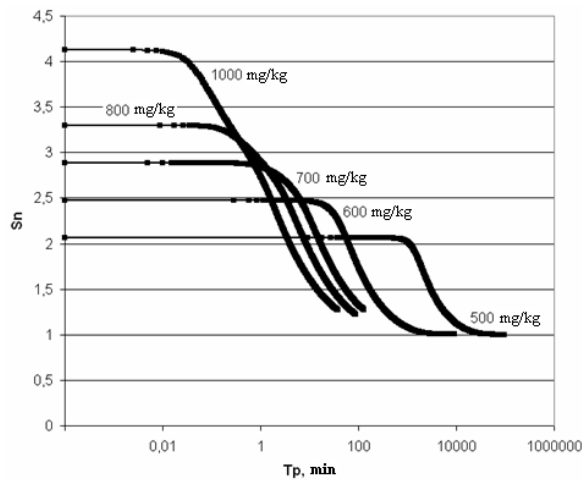

Fig. 8. The dependence of supersaturation S_N on time. $t=60^0C$, pH=8.

The results of simulation show that critical radius (nm) R_{cr} and induction time τ_{in} (min) increase when pH is stated and temperature becomes higher due to supersaturation reduce S_N. Consequently nucleation rate I_N reduces; it causes to increasing of final mean particles size R_A (nm).

Under the same temperature when pH reduces the surface tension σ_{sw} increases and rate of molecular deposition of silicic acid reduces. Owing to it critical radius of particles and induction time increase, nucleation rate reduces and final mean size of particles increases.
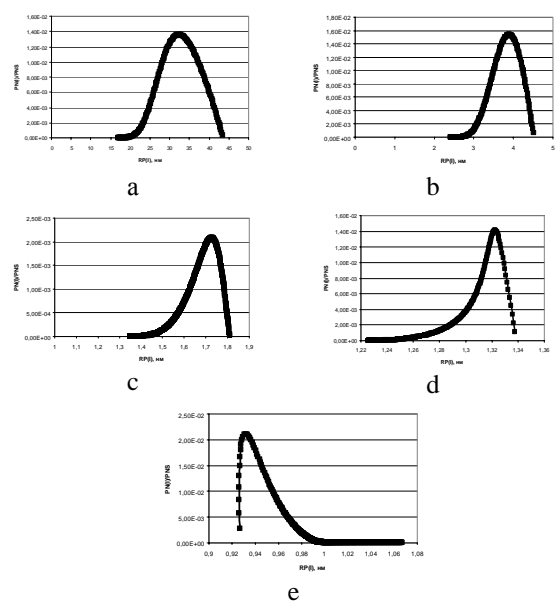

Fig. 9. The distribution of particles sizes under the temperature $t=60^0C$, pH=8. a – $C_S=500$ mg/kg; b – $C_S=600$ mg/kg; c – $C_S=700$ mg/kg; d – $C_S=800$ mg/kg; e – $C_S=1000$ mg/kg.

CONCLUSIONS

1. The results of numerical simulation show that in hydrothermal solutions the transformation of orthosilicic acid into colloidal silica happens as a result of two sequential processes: 1) homogeneous nucleation during which the transformation of orthosilicic acid into colloidal silica happens mainly as a result of increasing of new centers quantity; 2) heterogeneous nucleation which happens due to increasing of sizes of centers formed earlier if their quantity is practically constant. Durations of these stages depend on process parameters: temperature, pH, ionic strength, total silica content and supersaturation rate.

2. The results of numerical simulation show that the nucleation of orthosilicic acid molecules and formation of colloidal particles in hydrothermal solution actively develop under the temperature below $120-150^0C$. Under the temperature $120-150^0C$ and higher the induction time becomes comparable or exceeds time of heat carriers stay in wells, pipelines and processing units.

3. pH solution is an another factor considerably influencing on nucleation kinetics. When pH is low critical radius of particles increases considerably, the nucleation rate reduces and induction time increases. When pH is 7.0 and lower the induction time considerably exceeds the time of heat carrier movement in wells and thermal equipment.

4. The method on basis of numerical simulation carried out in the paper can be applied to project equipment for flow sheet of silica extraction from the hydrothermal solution during the stage of ageing. Such method gives a possibility to take into account how temperature profile, pH, ionic strength, concentration of solution components, duration of ageing during solution movement through the wells, pipe lines and equipment influence on final concentration and size of colloidal particles.

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