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SYNERGY OF HYDROMECHANICAL AND HYDROCHEMICAL PARAMETERS IN FORMATION OF SOLID DEPOSITS IN GEOTHERMAL AND OTHER WATERS

Article Highlights

- The efficiency of the solid deposits formation in the turbulent and laminar flow conditions of water is examined
- The critical flow velocity is lower in the geothermal waters, and higher in drinking water
- For different waters of approximately the same hardness, different critical flow velocities were obtained
- There is a significant impact of colloidal state on the formation of microdisperse system
- Mineralized waters contain colloidal matter and therefore have lower values of the critical flow velocity

Abstract

This paper deals with synchronised influences of hydromechanical and hydrochemical parameters on the formation of solid deposits in geothermal and other waters, which compose complex heterogeneous and micro-heterogeneous liquid-solid systems. The constituents of these waters in ionic, colloidal and micro-heterogeneous suspended liquid-solid states are responsible for the creation of carbonates, sulphates and other solid matters. In these processes, one cannot eliminate the influence of hydromechanical parameters with flow velocity and water flow criteria (laminar or turbulent flow) as vital factors. Experiments were conducted on the laboratory pilot installation with glass pipes of 2, 4, 6, 8 and 10 mm in diameter, respectively, and the flow was monitored by using a digital peristaltic pump with the flow rate of 2 ml/min to 5000 ml/min. The paper studies the impact of the linear flow velocity on the relative decrease of the initial water hardness in geothermal waters of Sijarinska Banja spa, Niška Banja spa and the estuary water of Medijana, Niš. From the obtained dependences, according to the linear regression model, for each diameter, critical values for linear velocities were determined, as an important parameter for the understanding of the synergism of the hydromechanical and hydrochemical parameters were determined.

Keywords: microturbulence, microdispersion systems, water hardness, critical linear velocity, solid deposits.

Geothermal, underground and other waters of high mineralization and high hardness comprise very complex composite heterogeneous systems playing a vital role in the energy efficiency, especially in distribution of such waters to certain consumers. Whether one uses geothermal waters in boilers and other heating systems, or in spas and rehabilitation centers, it is not possible to prevent the formation of solid deposits – incrustation.

Formation of solid deposits is caused by the presence of dissolved colloidal and suspended particles in water. Thus, water is not considered as a homogeneous phase but a micro-heterogeneous liquid-solid system, where in laminar conditions of

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flow, by means of crystallisation, coagulation and aggregation microheterogeneous areas and solid particles with boundary layer are created. In such flow conditions, each solid particle causes micro-hydrodynamics where in strictly laminar flow conditions a very developed micro-turbulent flow behind the particle is created.

Micro-turbulent flows in synergy with hydrochemical parameters can cause remarkably increased rates of mass exchange and in this way, growth of solid deposit particles. Thus, crucial importance is attributed to the particle-water system, whose functioning depends on the size and the shape of the particle and on the flow rate of the particle and of the water, or even particle and water together. The larger the mass of the solid particles and the more developed contact surface, the higher the inertia, and thus, closer the solid-fluid contact.

These founding basics are unique because of the introduction of the new concept of micro-hydrodynamics, based on the movement of very dispersive particles and aggregates through a liquid of certain surface tension and charge. Furthermore, one cannot neglect the effect of the mechanical bumping of certain particles in turbulent conditions in micro-areas, which enhances the parameters of sedimentation, crystallization and filtration processes, when we consider porous and dispersive deposits. Numerous causes of solid deposit formation due to high mineralization of these waters by calcium and magnesium salts [1–8], with the presence of certain impurities in dissolved and colloidal state, from the chemical point of view, are explained.

Having in mind a significant problem of solid deposit formation in geothermal, hydrothermal, and thermoenergy plants, where by rule one uses deionised water, a large body of research is based on the hypothesis that there is a synergy of hydrochemical and hydromechanical parameters in the creation of solid deposits – scale. The results shown in this paper are based on the assumption that for the formation of the scale it is important to have a laminar flow regime, with a laminar hydraulic border layer against the thicker pipe walls where diffusion and crystallization processes with mass transfer between the single constituents of different origin in water occur. The assumption is based on the fact that the surface charge of the pipe walls and the charge of colloidal particles in water cause their electrophoretic sticking and adsorption onto the surface, thus creating the conditions for the nucleation and crystal growth, *i.e.*, the sedimentation of solid deposits – scale [9–13].

This object of this study is not to analyse the hydrochemical parameters of de-balancing of calcium and magnesium bicarbonates (the ABC of the solid deposit formation [14]), *i.e.*, the changes that first lead to the creation of carbonate anion CO_3^{2-} and then to the creation of calcium and magnesium carbonates ($CaCO_3$ and $MgCO_3$); rather, it focuses on analysing the influence of a hydromechanical parameter (flow velocity) on the formation of solid deposits, and decrease of the initial water hardness.

The basic idea of this study is to enable monitoring scale formation at predetermined temperature, real hardness and other factors that disturb the hydrochemical balance of the formation of solid deposits, using a pilot installation, equipped with a digital peristaltic pump, through a set of different pipes of different diameters (ratio of length to diameter is much higher than 50), and laminar-piston flow of geothermal and other hard waters. The results should give answers to numerous disputable theoretical questions, as well as suggestions for practical solutions and designing systems for the distribution of geothermal and other waters.

EXPERIMENTAL

Materials and methods

In order to realize the designed program and research methodology, fresh samples of 80 dm^3 of the adequate initial hardness water were taken from Sijarinska banja, from the estuary of Aragon, Niška banja and the estuary of Medijana. Waters of Sijarinska banja and Niška banja contain metasilicic and metaboric acid in significant quantities (Table 1). The drinking water from the estuary of Medijana is groundwater that contains metasilicic and metaboric acid in very small quantities. Waters of Sijarinska banja and Niška banja contain geothermal calcium, magnesium hydrocarbonate.

Table 1. Contents of metasilicic and metaboric acid in waters of Sijarinska banja spa and Niška banja spa

Parameter	Sijarinska banja	Niška banja
Metasilicic acid content, mg/dm^3	0.1235	0.0293
Metaboric acid content, mg/dm^3	0.0372	0.0016
Temperature at the spring, °C	66	37.4

Equipment

The designed pilot installation (Figure 1) is composed of glass pipes, length of 1000 mm and dia-

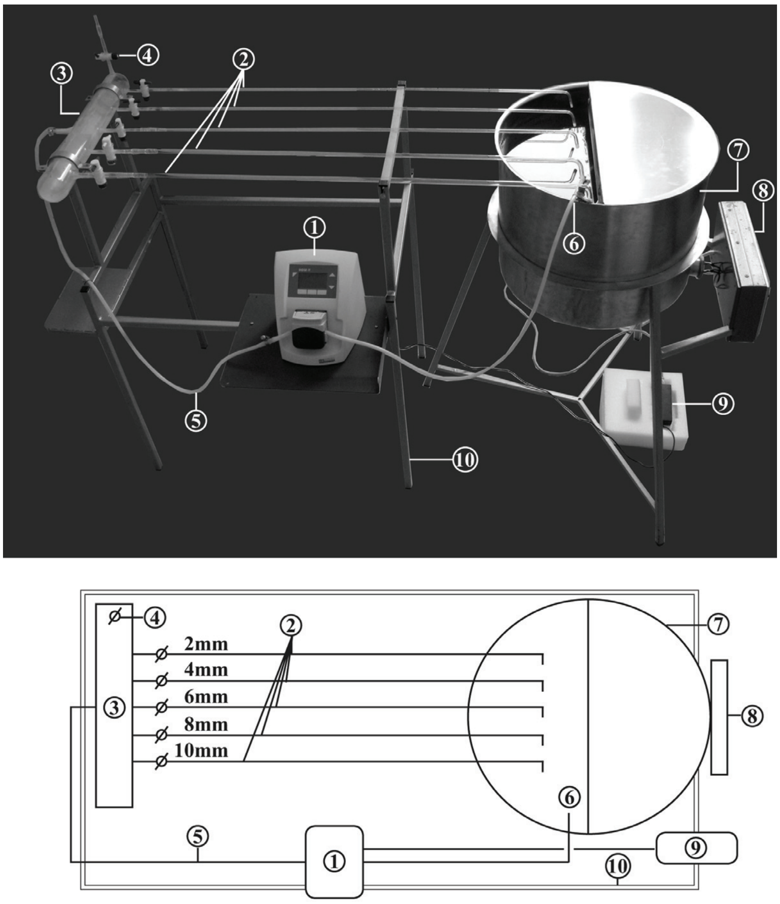


Figure 1. Pilot installation for hydraulic investigation of the influence of the flow velocity of geothermal and other hard waters on the process of solid deposit formation; 1 – pump, 2 – set of different diameters pipes, 3 – distribution splitting dish, 4 – degassing valve, 5 – silicon hose of the peristaltic pump, 6 – vacuum part of the silicon hose of the peristaltic pump, 7 – intake prochrome 80 l reservoir with heater, 8 – dashboard with thermostat and switcher, 9 – electrical energy supply, 10 – metal frame.

meters of 2, 4, 6, 8, 10 mm, respectively. All pipes were made of Pyrex glass by elongation so that equal conditions of pipe inner wall roughness were met. Flow and linear velocities are determined by the digital peristaltic pump DOSE IT P910 (INTEGRA Biosciences, Switzerland) with flows ranging from 0.6 ml/min to 5000 ml/min. Water temperature in the intake reservoir is controlled by a thermostat with constant temperature of 40 °C. In front of the set of pipes there is a glass splitting dish whose volume is designed to enable even flow through the system at the highest flows. A degassing valve is mounted on the splitting dish to avoid the occurrence of the gaseous phase in the solid-liquid system in laminar flow. Laminar (piston) flow is enabled by the ratio of the diameter and length of the pipe, because when this ratio is $L/D >> 50$, at any fluid velocity, conditions for laminar flow are provided.

Experimental procedure

For each sample of geothermal water and water from the estuary of Medijana Niš, immediately before the beginning of the experiment, a sample of water was filtered through blue ribbon filter paper and the initial hardness of water was determined. The water sample was then poured into the open 80 dm^3 boiler and the water flow was adjusted to the set flow. All taps on other glass pipes were closed and water flew only through the set pipe, with the fixed flow rate, then water was tempered at 40 °C. After 2 h, the pump was stopped, the water sample was filtered through blue ribbon filter paper and the final hardness was measured by the standard procedure (EDTA titrimetric method) [15]. Immediately after finishing one flow and after the residual water hardness measurement, the next measurement was performed on the same pipe, with other flows. The procedure was repeated for all other glass pipes from the set of pipes, as previously described. For each flow and diameter of the pipe, a flow velocity of water was calculated and the initial and final water hardness was determined. The obtained results were displayed graphically in the form of the dependence of the changes in water hardness on the water flow velocity. The obtained experimental findings were processed according to a linear mathematical regression model so as to reach corresponding dependences of the efficiencies of solid deposits formation in the function of flow velocity. In addition, from the maximal values of the efficiencies of solid deposits formation, at the inflection point, critical linear velocities of the fluid were determined, which in synergy with the hydrochemical parameters enable complex consideration of hydromechanical and hydrochemical parameters.

RESULTS AND DISCUSSION

Tables 2–4 show the results of the research conducted in order to investigate the influence of hydromechanical parameters on the change of the hardness of geothermal and other hard waters and the process of solid deposit formation for geothermal waters from Sijarinska banja, Niška banja and water from the estuary Medijana.

Mass flows expressed through the change of hardness per unit time at the pipe inlet G_{in} (°dH/s), can be expressed through the measured initial water hardnesses C_{in} (°dH/l) and flow through the pipe Q (l/s), as shown in Tables 2–4, in the following way:

$$G_{in} = C_{in}Q \tag{1}$$

Also, mass flow expressed as the change of hardness per unit time at the pipe outlet G_{out} (°dH/s), can be calculated from the mass flow at the pipe inlet G_{in} (°dH/s) and the efficiency of solid deposit formation (R) in the following way:

$$G_{out} = G_{in}(100 - R) \tag{2}$$

Efficiency of solid deposit formation (R) was calculated based on the mass balance and the results shown in Tables 2–4.

If for every single pipe diameter and flow (Tables 2–4 for different waters) the initial hardness is established as C_{in} = 100%, applying expressions (1) and (2) one can calculate percentages of mass flows at the pipe inlet ($G_{in.pr.}$) and at the pipe outlet ($G_{out.pr.}$) expressed as the change of hardness per time unit (°dH/s). Percentages of mass flows at the pipe outlet $G_{out.pr}$ are shown in Tables 2–4 for geothermal waters

Table 2. Research results for geothermal waters from Sijarinska banja spa

Flow (Q / ml min^{-1})	Pipe diameter (D / mm)	Linear velocity (υ / m s^{-1})	Reynolds number (Re)	Initial hardness (C_{in} / °dH)	Final hardness (C_{out} / °dH)	Efficiency of solid deposit formation (R / %)	Percentage outlet mass flow ($G_{out.pr.}$ / % °dH s^{-1})
37.5	2	0.20	605	3.69	3.58	2.98	0.0606
75	2	0.40	1209	4.17	3.90	6.46	0.1169
150	2	0.80	2419	4.42	4.22	4.57	0.2386
300	2	1.59	4838	5.50	5.03	8.57	0.4572
600	2	3.18	9675	3.71	3.56	4.04	0.9596
1200	2	6.37	19350	9.13	8.74	4.29	1.9141
1500	2	7.96	24188	8.70	8.30	4.60	2.3851
37.5	4	0.05	302	3.58	2.82	21.17	0.0493
75	4	0.10	605	3.90	3.70	5.16	0.1186
150	4	0.20	1209	4.22	4.16	1.59	0.2460
300	4	0.40	2419	5.03	4.66	7.34	0.4633
600	4	0.80	4838	3.56	3.3	7.30	0.9270
1200	4	1.59	9675	8.74	8.48	2.95	1.9409
1500	4	1.99	12094	8.30	8.17	1.57	2.4608
150	6	0.09	806	4.66	4.17	10.58	0.2235
300	6	0.18	1613	4.66	4.42	5.04	0.4748
600	6	0.35	3225	3.30	3.26	1.21	0.9879
1200	6	0.71	6450	8.48	7.92	6.61	1.8679
1300	6	0.77	6988	4.31	4.03	6.50	2.0259
1500	6	0.88	8063	8.17	6.94	15.06	2.1236
600	8	0.20	2419	3.22	3.19	0.93	0.9907
1200	8	0.40	4838	7.92	7.52	5.09	1.8982
1300	8	0.43	5241	3.86	3.64	5.70	2.0432
1500	8	0.50	6047	6.94	6.32	8.93	2.2767

Table 3. Research results for geothermal waters from Niška banja spa

Flow (Q / ml min^{-1})	Pipe diameter (D / mm)	Linear velocity (υ / m s^{-1})	Reynolds number (Re)	Initial hardness (C_{in} / °dH)	Final hardness (C_{out} / °dH)	Efficiency of solid deposit formation (R / %)	Percentage outlet mass flow ($G_{out,pr.}$ / % °dH s^{-1})
75	2	0.40	1209	11.90	11.70	1.68	0.1229
150	2	0.80	2419	12.40	12.00	3.23	0.2419
300	2	1.59	4838	12.90	12.50	3.10	0.4845
600	2	3.18	9675	12.80	12.40	3.13	0.9688
1200	2	6.37	19350	13.00	12.50	3.85	1.9231
1500	2	7.96	24188	13.00	12.50	3.85	2.4038
1800	2	9.55	29025	14.00	13.50	3.57	2.8929
75	4	0.10	605	11.70	11.50	1.71	0.1229
150	4	0.20	1209	12.00	11.70	2.50	0.2438
300	4	0.40	2419	12.50	12.00	4.00	0.4800
600	4	0.80	4838	12.40	11.80	4.84	0.9516
1200	4	1.59	9675	12.50	12.10	3.20	1.9360
1500	4	1.99	12094	12.50	11.90	4.80	2.3800
1800	4	2.39	14513	13.50	13.10	2.96	2.9111
150	6	0.09	806	11.70	11.60	0.85	0.2479
300	6	0.18	1613	12.00	11.80	1.67	0.4917
600	6	0.35	3225	11.80	11.70	0.85	0.9915
1200	6	0.71	6450	12.10	11.60	4.13	1.9174
1500	6	0.88	8063	11.90	11.50	3.36	2.4160
1800	6	1.06	9675	13.10	11.90	9.16	2.7252
300	8	0.10	1209	11.80	11.60	1.69	0.4915
600	8	0.20	2419	11.70	11.40	2.56	0.9744
1200	8	0.40	4838	11.60	11.30	2.59	1.9483
1500	8	0.50	6047	11.50	11.20	2.61	2.4348
1800	8	0.60	7256	11.90	11.60	2.52	2.9244

Table 4. Research results for geothermal waters from Medijana estuary

Flow (Q / ml min^{-1})	Pipe diameter (D / mm)	Linear velocity (υ / m s^{-1})	Reynolds number (Re)	Initial hardness (C_{in} / °dH)	Final hardness (C_{out} / °dH)	Efficiency of solid deposit formation (R / %)	Percentage outlet mass flow ($G_{out,pr.}$ / % °dH s^{-1})
75	2	0.40	1209	12.60	12.10	3.97	0.1200
150	2	0.80	2419	12.50	12.20	2.40	0.2440
300	2	1.59	4838	15.40	14.80	3.90	0.4805
600	2	3.18	9675	15.50	14.90	3.87	0.9613
1200	2	6.37	19350	13.60	13.10	3.68	1.9265
1500	2	7.96	24188	14.60	14.40	1.37	2.4658
1800	2	9.55	29025	14.90	14.34	3.76	2.8872
75	4	0.10	605	12.10	11.90	1.65	0.1229
150	4	0.20	1209	12.20	12.00	1.64	0.2459
300	4	0.40	2419	14.80	14.60	1.35	0.4932
600	4	0.80	4838	14.90	14.80	0.67	0.9933
1200	4	1.59	9675	13.10	12.70	3.05	1.9389
1500	4	1.99	12094	14.40	14.00	2.78	2.4306
1800	4	2.39	14513	14.34	13.55	5.47	2.8359
150	6	0.09	806	12.00	11.60	3.33	0.2417
300	6	0.18	1613	14.60	14.40	1.37	0.4932
600	6	0.35	3225	14.80	14.60	1.35	0.9865

Table 4. Continued

Flow (Q / ml min^{-1})	Pipe diameter (D / mm)	Linear velocity (υ / m s^{-1})	Reynolds number (Re)	Initial hardness (C_{in} / °dH)	Final hardness (C_{out} / °dH)	Efficiency of solid deposit formation (R / %)	Percentage outlet mass flow ($G_{out.pr.}$ / % °dH s^{-1})
1200	6	0.71	6450	12.70	12.50	1.57	1.9685
1500	6	0.88	8063	14.00	13.70	2.14	2.4464
1800	6	1.06	9675	13.55	12.86	5.11	2.8468
600	8	0.20	2419	14.60	14.50	0.68	0.9932
1200	8	0.40	4838	12.50	12.40	0.80	1.9840
1500	8	0.50	6047	13.70	13.50	1.46	2.4635
1800	8	0.60	7256	12.86	12.43	3.34	2.8997

from Sijarinska banja, Niška banja and drinking water from the estuary Medijana.

Dependences of the efficiences of solid deposits formation R, in different diameter pipes on the flow velocity (υ for geothermal waters from Sijarinska banja, Niška banja and water from the estuary Medijana are shown in Figures 2a-c.

For geothermal waters the efficiency of solid deposits formation in small diameter pipes is the highest in the range of flow velocities from 0.5 to 1.0 m/s (Figures 2a and b), whereas for the geothermal waters from the estuary Medijana that range was shifted to velocities of 1.0 to 2.5 m/s (Figure 2c). The highest efficiency of solid deposits formation in this range is calculated for higher flows (Q = 1500 ml/min and Q = 1800 ml/min), when turbulent flow is inevitable in pipes. On the other hand, due to the occurrence of the microturbulent flow in the area behind solid particles in motion, the conditions are created for the high exchange of mass and the occurrence of very dispersive particles in the form of slurry, which disturbs the muddiness of the water and does not deposit on the dish walls, *i.e.*, it is easily washed away by fluid flow. Also, by the creation of relatively porous mass in hot water systems again, conditions are created for the transformation from the turbulent into the laminar flow regime through the narrow and irregular channels between the single grains. Thus, conditions for sedimentation that are valid for the laminar regime are once again created, which is another reason to coat the whole hot water or pipeline system with a relatively compact thin layer of solid deposit.

Experimental results have confirmed that, regardless of the cross-section of the pipe, there is a critical flow velocity when the efficiency of solid deposits formation in small diameter pipes is the highest, and when the biggest change of the initial water hardness occurs. In further analysis, experimental results of the flow velocities and corresponding calculated mass flows on the pipe outlet (Tables 2-4) for each pipe diameter were each fitted according to the linear mathematical regression model, which can be expressed by:

$$G_{out.pr.} = a\upsilon + b \tag{3}$$

where a and b are the coefficients of linear regression, determined by the method of the smallest squares on the basis of the data on flow velocities and corresponding calculated percentage of mass flows on the pipe outlet. Agreement of the experimental data with the model is determined based on the correlational coefficient r^2, obtained after the linear fitting. Parameters of the linear regression model for the dependences of the outlet mass flow on the linear velocity for different pipe diameters, for the waters from Sijarinska banja, Niška banja and water from the estuary Medijana are given in Table 5, and families of lines representing dependencies of the outlet mass flow on the flow velocity are shown in Figure 3.

The experimental results confirm that there is a linear correlation between the mass flow (change of the water hardness per unit time) at the pipe outlet and flow velocity for different pipe diameters, which allows for simple calculations of the outlet water hardness. Therefore, for any inlet hardness C_{in} (°dH/l) and pipe flow Q (l/s), based on the calculated percentage mass flow on the pipe outlet $G_{out.pr.}$ (%°dH/s), one can define the outlet hardness C_{out} (°dH/l) using Eq. (4):

$$C_{out} = C_{in}\frac{G_{out.pr.}}{Q}\frac{1}{100} \tag{4}$$

As can be seen from the previous analysis and discussion of results, this study considers all the changes of water hardness as a function of the hydromechanical parameters, as one of the hydrochemical criteria, so as to better define the synergy of the hydromechanical and hydrochemical parameters.

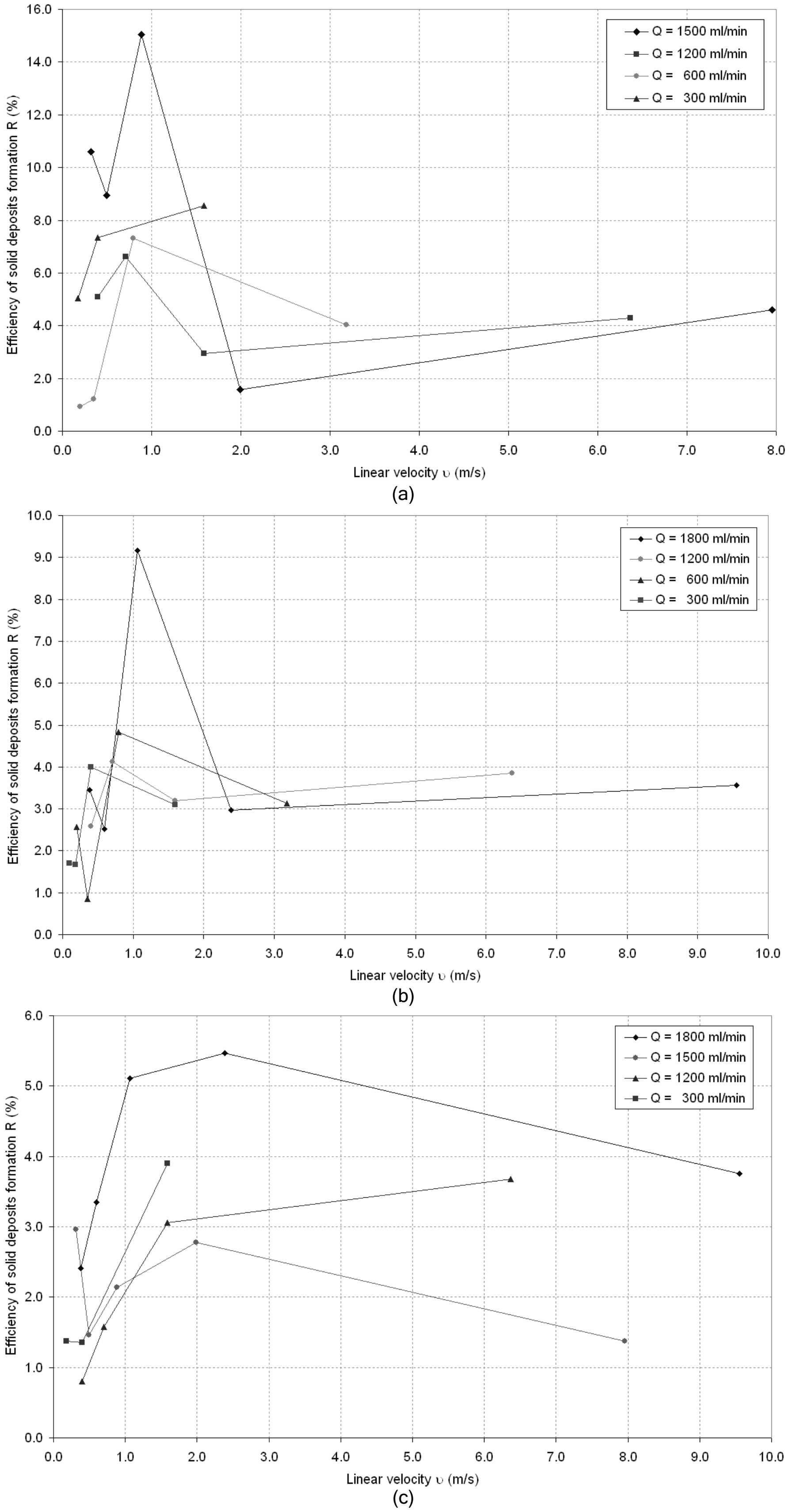
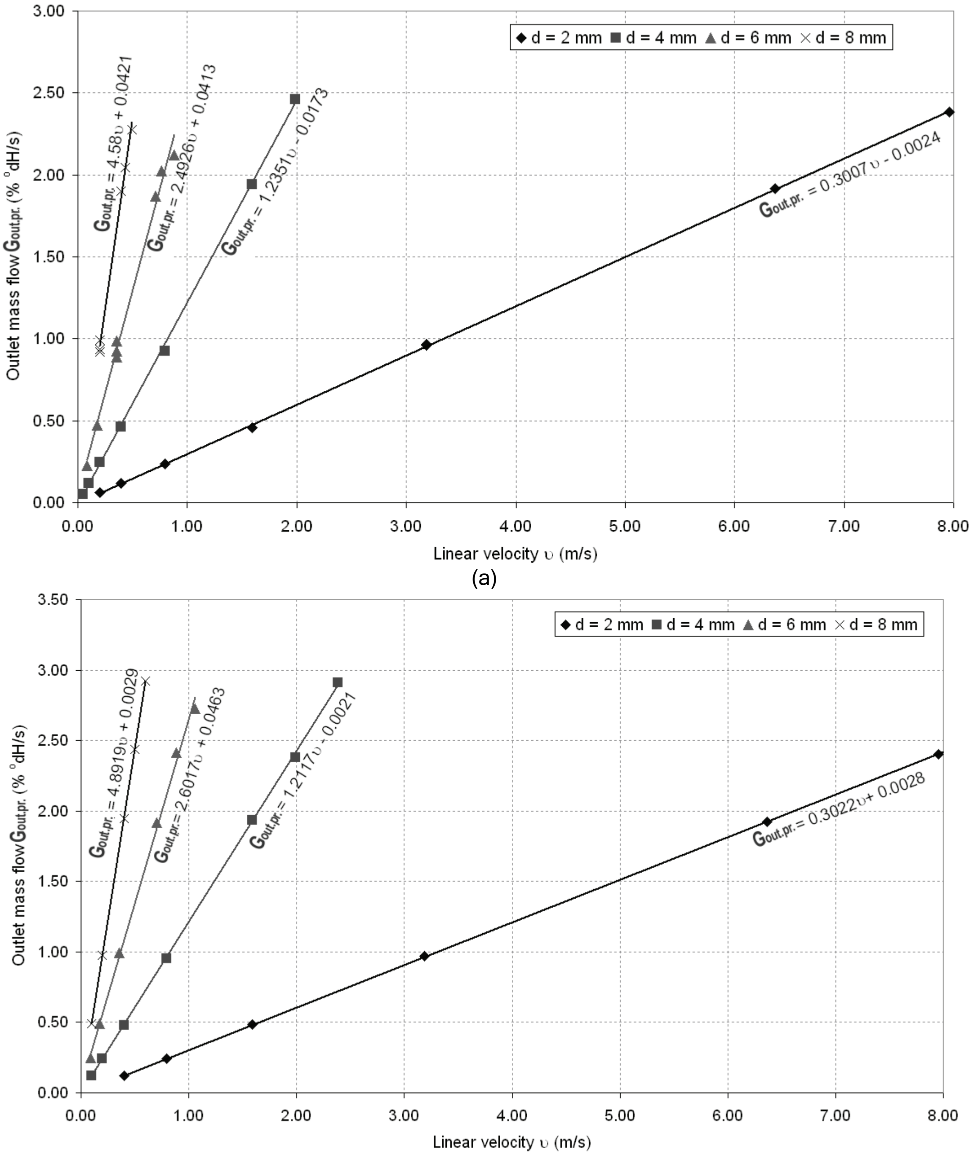
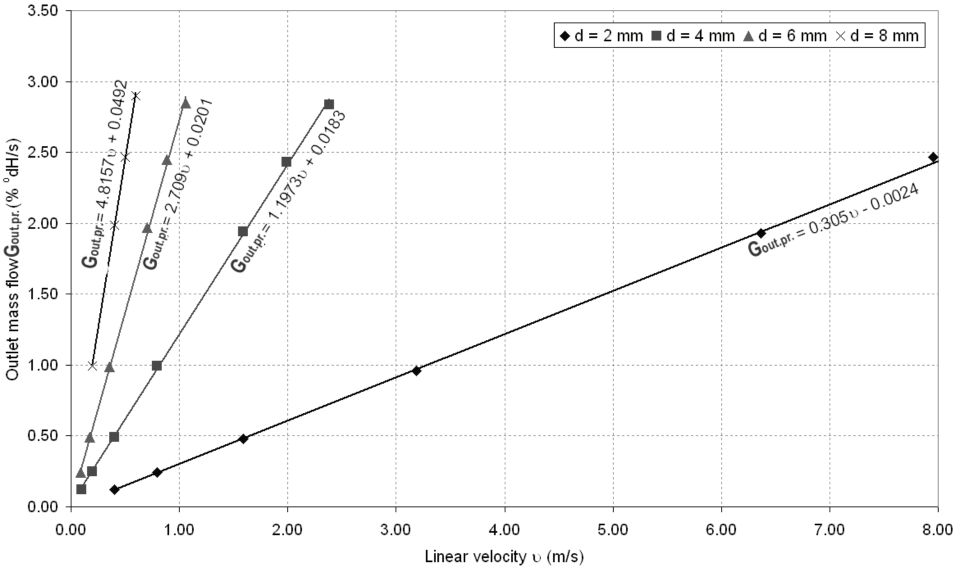


Figure 2. Dependence of the efficiencies of solid deposits formation in different diameter pipes on the flow velocity for geothermal waters from a) Sijarinska banja, b) Niška banja and c) estuary Medijana.

Table 5. Parameters of the linear regression model for different pipe diameters

Examined water sample	Pipe diameter (D / mm)	Coefficient a	Coefficient b	Linear regression model	Correlational coefficient r^2
Sijarinska Banja	2	0.3007	-0.0024	$G_{out.pr.} = 0.3007\upsilon - 0.0024$	0.9999
	4	1.2351	-0.0173	$G_{out.pr.} = 1.2351\upsilon - 0.0173$	0.9995
	6	2.4926	0.0413	$G_{out.pr.} = 2.4926\upsilon + 0.0413$	0.9915
	8	4.5800	0.0421	$G_{out.pr.} = 4.5800\upsilon + 0.0421$	0.9966
Niška Banja	2	0.3022	0.0028	$G_{out.pr.} = 0.3022\upsilon + 0.0028$	1.0000
	4	1.2117	-0.0021	$G_{out.pr.} = 1.2117\upsilon - 0.0021$	0.9998
	6	2.6017	0.0463	$G_{out.pr.} = 2.6017\upsilon + 0.0463$	0.9974
	8	4.8919	0.0029	$G_{out.pr.} = 4.8919\upsilon + 0.0029$	1.0000
Medijana	2	0.3050	0.0024	$G_{out.pr.} = 0.3050\upsilon - 0.0024$	0.9997
	4	1.1973	0.0183	$G_{out.pr.} = 1.1973\upsilon + 0.0183$	0.9995
	6	2.7090	0.0201	$G_{out.pr.} = 2.7090\upsilon + 0.0201$	0.9992
	8	4.8157	0.0492	$G_{out.pr.} = 4.8157\upsilon + 0.0492$	0.9993





(c)

Figure 3. Dependences of the outlet mass flow on the flow velocity for different pipe diameters for the geothermal waters of a) Sijarinska banja, b) Niška banja and c) Medijana estuary water.

Further explanations of the phenomena and processes would go deeper into the above-mentioned synergy and are beyond the scope of this paper. The complex phenomena of solid deposits formation under the influence of hydromechanical and hydrochemical parameters demand more in-depth analysis and explanation of all processes occurring in the boundary layer. Our focus is mainly directed at the processes in the static border layer around each dispersive particle, agglomerate or deposit, taking into account electrostatic phenomena, fluid surface tension, surface roughness, viscosity and other relevant factors. Previous research findings point to the possible microturbulences in the totally static and laminar layer as a consequence of the inertia of fluid flow by dispersive, agglomerate aggregates and other solid deposits. The research program and methodology of this paper have confirmed the set basics and have pointed to the explanation model of the synergy between micro- and macro-hydrodynamic parameters and hydrochemical and chemical parameters of solid deposits formation.

CONCLUSION

Expected changes in hydrochemical parameters affected by the hydromechanical parameters were found. The basic indicator of the changes in hydrochemical parameters is the rate of change in water hardness per unit time (°dH/s) found for different flows through glass pipes of different diameters. Flow velocity (its critical value) was considered as the main hydromechanical parameter, which provides the highest contribution of deposit in the investigated waters. Different values for the critical flow velocities ranging from υ_{crit} 0.5-1 m/s were found for the waters in Sijarinska and Niška banja. The drinking water of Medijana showed remarkably higher critical values of the flow velocity of 1-2.5 m/s. On the other hand, the highest efficiency of solid deposits formation was found in the highest flows, where besides the microturbulence there was also macroturbulence. Critical flow velocity when the efficiency of solid deposits formation in pipes is the highest, *i.e.*, when the largest change in the inlet water hardness occurs, does not depend on the cross-sectional area of the pipe. The correlation between the change in the water hardness at the pipe outlet and flow velocity for different pipes is linear. Applied modelling thoroughly describes the hydrodynamic parameters.

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NAUČNI RAD

SINERGIZAM HIDROMEHANIČKIH I HIDROHEMIJSKIH PARAMETARA U PROCESU STVARANJA ČVRSTIH DEPOZITA U GEOTERMALNIM I DRUGIM VODAMA

Predmet ovog rada je sinhronizovano dovođenje hidromehaničkih i hidrohemijskih parametara procesa stvaranja čvrstih depozita u geotermalnim i drugim vodama, koje činesložen heterogeni i mikroheterogeni sistem tečno-čvrsto. Prisutni sastojci u ovim vodama u jonskom, koloidnom i mikroheterogenom suspendovanom stanju čvrsto-tečno, odgovorni su za stvaranje karbonata, sulfata i drugih čvrstih materija. U ovim procesima se ne može izbeći uticaj hidromehaničkih parametara, gde bitnu ulogu imaju linearna brzina i kriterijumi strujanja vode. Eksperimenti su izvedeni na laboratorijskom pilot postrojenju sa staklenim cevima prečnika 2, 4, 6, 8 i 10 mm, a protok je kontrolisan digitalnom peristaltičkom pumpom sa intervalom protoka od 2 do 5000 ml/min. U radu su prikazani rezultati istraživanja uticaja linearne brzine strujanja na relativno smanjenje polazne tvrdoće vode, a odnose se na geotermalne vode Sijarinske banje, Niške banje i za vodu iz izvorišta Medijana, Niš. Eksperimentalno dobijeni rezultati linearnih brzina i sračunati protoci na izlazu iz cevi malih preseka, fitovani su prema linearnom regresionom modelu za svaki prečnik. Iz dobijenih zavisnosti, utvrđene su kritične vrednosti za linearne brzine, kao važnog parametra za sagledavanje sinergizma hidromehaničkih i hidrohemijskih parametara.

Ključne reči: mikroturbulencija, mikrodisperzni sistemi, sinergizam, hidromehanika, tvrdoća vode, kritična linearna brzina, čvrsti depoziti.