BULETINUL INSTITUTULUI POLITEHNIC DIN IAŞI
Tomul L (LIV), Fasc. 1–4, 2004
CONSTRUCŢII. ARHITECTURĂ



D.C. 628

# A METHOD TO EMPHASIZE THE TARTAR DEPOSITS EFFECT ON THE PERFORMANCES OF "SANITARY INSTALLATION" SYSTEM

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The main interest of this paper generally refers to the results of an analysis regarding the influences of the tartar deposits effect on the water supply plumbing systems (mainly warm water installations made of steel pipes or polar plastic materials). The disfunctional effect due to this effect has as consequence the increase of the linear pressure loss and the decrease of the service pressure of the consumers. To emphasize the effect of the tartar impurity deposit of the time behavior for the sanitary plumbing systems, the analysis was made using the MATLAB program facilities for the simulation of this phenomenon. The model allows several propositions to include the impurities deposit effect in the standard method to design the installations.

## 1. Introduction

During the service period of the water supply plumbing systems (mainly warm water installations made of steel pipes or polar plastic materials) has been observed disfunctional effects due to the decrease of the service pressure of the far positioned consumers.

The diagnosis for these installations during the repairing measures emphasized that missing the efficient treatment systems, the flowing section is substantially decreasing as consequence of a tartar impurity deposit and its thickness continuous growing.

From the practice point of view it is interesting to quantify the influence of the tartar impurity deposit on the global performances of the installations to avoid the disfunctionalities generated by this effect.

The design methods to conceive performant water supply installations (considering the real time water-installation behavior) have a decisive importance on their global performances. At the present these methods do not adequately reflect the particularities of the individual performances of the components elements (specially materials) concerning the tartar impurity deposit.

To improve the calculation methods to include all these aspects, the authors have created a model, which allows the simulation of the real time behavior of the installations. To realize this model has been used specialized functions from the Symulinc toolbox of the MATLAB programming medium.

## 2. The Causes of Tartar Impurity Deposit Appearance Phenomenon. Curative Treatment and their Efficiency

The water has a remarkable solvent power and it is not a pure substance, containing composed mineral or organic elements and atmospheric gases. Consequently, it is not neutral from the electro-chemical point of view. It does not keep the structure stability with the temperature variations. Continuously instable its evolution is marked by two types of exchanges: one of internal state and an other one with the environment. These two interdependent phenomena are equally physical, chemical and biological. Running the water through the installations components bring the manifestation of the reciprocal interaction: water–material–installation.

One of the effects exerted by water on the installations components are due to the water property to store more or less the limestone. To quantify the tartar deposit effect on the water supply installations it is necessary to identify the causes, which are the basis of its manifestation, and to quantify them.

The running water contains, in a bigger or a smaller proportion, calcium and/or magnesium carbonates which ionize leading to the separation into calcium ions ($Ca^{2+}$) and hydrogen-carbonate ions ($HCO_3^-$) which are no stable than in the presence of a certain solved quantity of carbon dioxide ($CO_2$).

To be able to appreciate the behavior of a specific quality of water toward the installation material it is necessary to know the quantity of carbon dioxide which must to accompany the hydrogenate ions to maintain them soluble, respectively inert, from chemical point of view.

The quantity of solved carbon dioxide, which maintains the stability, and solubility of the hydrogen-carbonates ions, is usually named *equilibrium* $CO_2$.

The bicarbonates are very instable elements, that can easily react to any change of the water temperature or of the carbon dioxide content reactions, which can be of decomposition or of combination of the $CO_3^{2-}$ ions with the $Ca^{2+}$ ions present in the water.

So, the general tendency of the water in contact with a material is to participate, either to solubility reactions of carbonates ($CaCO_3$) or of decomposition of the bicarbonates (function of the water properties) until a state of equilibrium, practically made by the state of equilibrium between the calcium and the carbonic gases compounds (carbonates and hydrogen carbonates). The equilibrium reaction is a reversible one.

The movement toward a sense or an other one comparing with the state of equilibrium are the consequence of:

a) temperature variation;

b) hydrogen-carbonates ions concentration change in water;

c) carbon dioxide ions concentration change in water.

The equilibrium state it is characterized through a value of the pH named the *equilibrium pH*. Function of pH value the water character is appreciated as being:

a) *aggressive* (has the quality to solve the calcium carbonate) when the water's pH is inferior w.r.t. the equilibrium pH value;

b) *neutral*, when the water's pH is equal with the equilibrium pH value;

c) *stratum deposit* (has the quality to store calcium and magnesium carbonates), when the water's pH is superior to the equilibrium pH value.

The calcium-carbonic equilibrium of the water can be evaluated having in view the elements referring to the water characteristics.

There are different methods to evaluate this equilibrium. The main suggested methods in the technical literature are:

a) Poirier et Legrand method.

b) Tillmans' tables.

c) Franguin – Marécaux diagramm.

d) The Hollopean and Dubin[1]graph.

e) The Hoover and Langelier[2]graph.

f) The Ryznar[3]index.

From all the methods, *the method Poirier–Legrand's is a rigorous one*, which considers all the elements involved in the process. This can be successfully used thanks to the facilities offered by micro-informatics. The others methods have a relatively limited applicability.

It must be specified that the water pH can be easily measured but the tartar storage capacity, *respectively the power to store stratums of substance is difficult to estimate.*

In present, practically there it not exist a measurement apparatus to allow an easy and quick quantification of the tartar storage capacity.

The quality of materials to help the tartar storage is different. In the technical literature is shown a qualitative classification (Table 1).

[1]Can provide information referring to the quantity of limestone susceptible to be stored, respectively solved. Can not be applied than for not sweeten waters.

[2]Allow the water saturation pH calculation function of the saltiness, the Ca content, the hidrogen-carbonates ions and temperature.

[3]It is established empirically, based on the saturation pH extracted from the Hoover and Langelier graph. Can be calculated using the relation $IR = 2\text{pH}_s - \text{pH}$.

Table 1

| Anti-tartar system type | The stability of the running water temperature $\Delta T$, [°C] | The tartar thickness on the walls of the water preparation apparatus, [cm] | Tartar presence index in aval of preparator |
|---|---|---|---|
| With poliphosphates | 3.2 | 0 | – |
| With poliphosphates | 2.3 | 0 | – |
| Electromagnetic | 8.0 | 1.9 | □ |
| Electromagnetic | 3.3 | 2.7 | □□□ |
| With ions changes | 4.7 | 2.5 | □□ |
| With ions changes | 2.8 | 2.4 | □□□ |
| Magnetic | 3.8 | 3.6 | □□ |
| Magnetic | 3.7 | 3.2 | □ |
| Magnetic | 7.0 | 2.3 | □□ |
| Sweeten | 4.7 | 2.1 | □ |
| Sweeten | 6.3 | 1.1 | – |
| – | 3.1 | 2.4 | □ |
| – | 3.6 | 2.7 | □ |

□ – small number of limestone particles;
□□ – big number of limestone particles blocking the electro-vane;
□□□ – very big number of limestone free particles in installation after the warm water preparation apparatus.

As a conclusion, concerning *the origin of the tartar formation and storage there are two big categories of elements, i.e. calcium salts (carbonates, sulphates, phosphates and silicates) and silica.*

a) *Calcium carbonates*, which are much more soluble to high temperatures, adhere very easy to the polar materials surfaces (metals in which started a corrosion process, PVC), the adherence process being much more accelerated to high temperatures. The forming speed is very increased. At a higher circulation speed the water get into the flow excepting the carbonates crystals, which cannot adhere to the contact material. These are then transported up to the areas with a smaller circulation speed, leading to the stratum deposit forming.

b) Concerning the calcium sulphate and silica, these ones do not lead to the tartar forming in the cold or warm water supply installations.

*The effects of tartar deposits formed on the installations are multiples, namely:*

a) the change of the hydraulic characteristics of the installation through the flow section reduction;

b) obstruction of the pipes or of the apparatus;

c) blocking of the taps and of the security organs;

d) the increase of the exchange surfaces thickness with negative effects on the efficiency, ageing exchange efficiency process;

e) the creation of porosity with bad consequences as a result of helping the favour of differential air flowing and microorganisms growth;

f) the forming and growth of dangerous microorganisms for the human health (*e.g. legionella*).

*Useful prescriptions for the design activity referring to the quantification of the tartar deposit effect in the water supply installations the authors did not found in tech-*

*nical literature of this special domain. But the technicians recommend the treatment technologies (apparatus) to prevent the tartar forming effect, but theirs efficiency is quite improbable.*

Well known laboratories in the world (France, England, Switzerland, Japan, etc.) have been tested the efficiency of some anti-tartar systems provided by different producers. Among them there is C.S.T.B. from France. The C.S.T.B. study relates about the testing of the behavior of an installation for preparation and distribution of warm water small capacity (unifamilial)[4], equipped or not with different anti-tartar apparatus, in an interrupted functioning regime as follows "*5 min: functioning, 5 min: pause*"[5], during a four months period. The test emphasized the appearance of some tartar deposits with thick ness ranging from 1.1 mm to 3.6 mm (Table 1).

That proves a unefficiency of the anti-tartar systems, exception the treatment apparatus with silico-phosphates like. On the other hand, the relative high value of the tartar deposits (average 3 mm on a $1/2''$ pipe during 10 years period) in normal functioning conditions it may be noticed.

It clearly appears the necessity to consider the effect of tartar deposits in the activity of water supply installations design.

## 3. A Method to Emphasize the Tartar Deposits Effect on the Performances of "Sanitary Installation" System

As earlier stated the forming of the tartar deposit has as effect the continually decrease of the following section of the water with the consequence of the increase of the running water speed (for the same flow of water demand) and implicitly of the linear and local charge losses.

The increase of the load losses train up the increase of the necessary pressure for the transportation of the same flow of water on the same installation and finally the increase of the energy consumption in exploitation.

The energy consumption in exploitation may be expressed through the general relation:

$$W_{e,a} = \int_0^T \left(\sum_i P(i,\tau)\right) \mathrm{d}\tau = \int_0^T \left[\sum_i \frac{Q(i,\tau)\rho g H(i,\tau)}{\eta}\right] \mathrm{d}\tau,$$

where: $P(i,\tau)$ is the electric power consumed per time unit[6] to run the water through the $i$ sections of the unfavourable route[7], [kWh/year]; $\tau$ – the time of integration, respectively the functioning period, [years][8]; $\rho$ – the water density at the circulation temperature, [kg/m$^3$]; $\eta$ – the functioning output of the installations for the pressure

[4]Equipped with a warm water apparatus type semi-instantly with gas, 23 kW, and ZnOl pipe net.

[5]Equivalent functioning regime with 10 years normal use.

[6]Usually it is of interest the consumed electric power per year.

[7]From the disadvantaged consumer untill to the calculation section of the $i$ route.

[8]Can be also chosen an other unity (*i.e.* [days], [hours]) function of the followed purpose in the study.

increase; $Q_i$ – the water flow arrived in the section $i$ of the installation, $[\mathrm{m}^3/\mathrm{h}]$; $H_i$ – the necessary pressure in the calculation section $i$. It is generally of interest the pressure in the point of connection which may be determined with the relation:

$$H_i = \sum H_{g,i} + H_u - H_r + \sum h_{ri,i}, \quad [\mathrm{m\,H_2O}],$$

where: $H_r$ is the available pressure in the public net in the point of connection, $[\mathrm{m\,H_2O}]$; $H_u$ – the use pressure of the most unfavourable consumer, $[\mathrm{m\,H_2O}]$; $H_{g,i}$ – the geodesic quotation (toward the point of connection) of the most unfavourable consumer, $[\mathrm{m\,H_2O}]$; $\sum h_{ri,i}$ – the charge loss sum, $[\mathrm{m\,H_2O}]$, determined with the relation:

$$h_{r,i} = h_{ri,i} + h_{rl,i} = \lambda_i \frac{l_i}{d_i} \cdot \frac{v_i^2}{2g} + \xi_i \frac{v_i^2}{2g}, \quad [\mathrm{m\,H_2O}],$$

where: $h_{r,i}$ represents the total charge loss on the $i$ route; $h_{rl,i}$ – the local charge loss on the $i$ route; $\lambda_i$ – the linear charge loss coefficient on the $i$ route; $\xi_i$ – the local charge loss coefficient on the $i$ route; $v_i$ – the average value of the running water speed through the pipe on the $i$ route; $d_i$ – the interior diameter of the pipe of the specific route; $l_i$ – the $i$ pipe route length; $g$ – the gravity acceleration.

The quantification of the tartar deposit effect on the installation can be made through the evaluation of the supplementary energy consumption in exploitation equal with the value of the necessary energy consumption to counteract the supplementary charge losses.

*The phenomenon can be described defining a time variation function of the diameter in relation with the dimensions of the deposit.*

It is introduced the notion of *speed forming of the tartar deposit*, $v_{\mathrm{deposit}}$, [mm/year][9], *as being the thickness of the tartar deposits during one year period.*

The speed forming of the tartar deposit depends on:

a) the material nature of the pipe (with polarized or neutral molecules as electric charge);

b) the running water properties meaning: water temperature; water pressure; water quality, which may varies within accepted limits by the drinking water conditions, respectively its ionic composition and specially: calcium ions concentration ($Ca^{++}$); carbonates ions concentration ($CO_{3-}$); hydrogen carbonates ions concentration ($HCO_3$); the active carbon dioxide content depending on the type of the high pressure station and the pressure variation in the installation;

c) the running water flow, respectively the running water speed.

The pipe diameter will be affected in time in accordance with relation:

$$d_i(\tau) = d_i(\tau_0) - \int_0^\tau v_{\mathrm{deposits},i}\,\mathrm{d}\tau. \tag{1}$$

[9]Has been chosen the time unity "year" because the most experimental data found in the technical specialty literature referring to the thickness of the tartar stratum stored are indicated in mm/year.

If the time of integration, $\tau$, is considered equal with the life time periods of the installations (50 years) and the time variation interval there is an year it results that $v_{\text{deposits},i}$ is equal to the average annual value tartar forming speed.

The upward relation becomes:

$$d(i,\tau,T) = d(\tau_0,T) - v_{\text{deposits},i,T}\tau, \tag{1'}$$

where: $v_{\text{deposits},i,T}$ is the average speed of the tartar forming deposits, [mm/year], at the temperature $T$; $\tau$ – time, [years].

*From a theoretical point of view the speed of the tartar forming deposit can be estimated function of the developing speed of the processes/chemical reactions* which represents the measurement of developing in time of the chemical reactions.

*Consequently for a $d_i$ route diameter can be determined*:

a) *the variation in time of the mass of the adherent precipitates* as being

$$m_{\text{deposits},i,j,\tau,T} = \int_\tau \sum_{j=1}^{p} m_{i,j,\tau,T}\,\mathrm{d}\tau,$$

where: $p$ represents the number of distinct components of the formed adherent precipitates, $i$ – the route number and $\tau$ – the time of the integration;

b) *the variation in time of the volume of the formed adherent precipitates*

$$V_{\text{deposits},i,j,\tau,T} = \int_\tau \sum_{j=1}^{p} V_{i,j,\tau,T}\,\mathrm{d}\tau.$$

If it is admitted that the storage of the precipitates on the pipe walls is uniformly realized, than the adherent precipitates volume can be expressed as a function of the speed of the tartar forming deposits with the relation:

$$V_{\text{deposits},i} = \left(\frac{\pi d_{i,0,T}^2}{4} - \frac{\pi d_{i,\tau,T}^2}{4}\right) l_i = \left[\frac{\pi d_{i,0,T}^2}{4} - \frac{\pi(d_{i,0,T} - 2v_{\text{deposits},i,\tau,T})^2}{4}\right] l_i, \tag{2}$$

where: $d_{i,0,T}$, $d_{i,\tau,T} = d_{i,0,T} - 2v_{\text{deposits},i,\tau,T}$, represent the calculation section diameter, $i$, at the initial moment, respectively at the moment $\tau$ and the temperature $T$, $v_{\text{deposits},i,\tau,T}$ – the global speed of the tartar forming deposit; $l_i$ – the length of the pipe route $i$ for which it is made the estimation.

*So, the global speed of the tartar forming deposit can be expressed as function of the sediment precipitates volume, respectively function of their mass*, with the relation:

$$\sum_{j=1}^{p} \frac{m_{i,j,T}(\tau)}{\rho_{i,j,T}} = \left[\frac{\pi d_{i,0,T}^2}{4} - \frac{\pi(d_{i,0,T} - 2v_{\text{deposits},i,\tau,T})^2}{4}\right] l_i. \tag{3}$$

Finally, the expression of the speed variation of the tartar formed deposits becomes:

$$v_{\text{deposits},i,\tau,T} = \frac{d_{i,0,T}}{2} \pm \sqrt{\frac{d_{i,0,T}^2}{4} - \frac{1}{\pi l_i}\sum_{j=1}^{p}\frac{m_{i,j}(\tau,T)}{\rho_{i,j,\tau,T}}}. \tag{4}$$

As a conclusion it may be observed the speed of the tartar that formed deposits can be practically *expressed, in an other scale, function of the mass of the adherent precipitates formed on the walls of a pipe having the diameter d, in certain conditions of salts content (ionic charge), of temperature, of pressure, of circulation flow, and, respectively, of material for the pipe in contact with the water.*

As stated before the stratum depositor power of the water and mostly the speed of the tartar storage deposit are quite difficult to estimate.

*Practically, at present there is no quick and easy quantification instrument found for the tartar deposits.*

Now they are deduced crossing many criteria (*e.g.* the Poirier – Legrand method based on the search of the minimal energy of the system for certain testing conditions).

## 4. Conclusions

1. The simulation of the real behavior of a distribution warm water installation produced from cold drinking water without special treatments (for a $P+4E$ building and a 50 years life time functioning) leads, according to the research made by the authors to the following conclusions:

a) The necessary pressure to provide the warm water flow considered in the design hypothesis substantially increases with the time development, as a consequence of the tartar storage raging from 18.3 m $H_2O$ to 25.249 m $H_2O$ (Fig. 1).

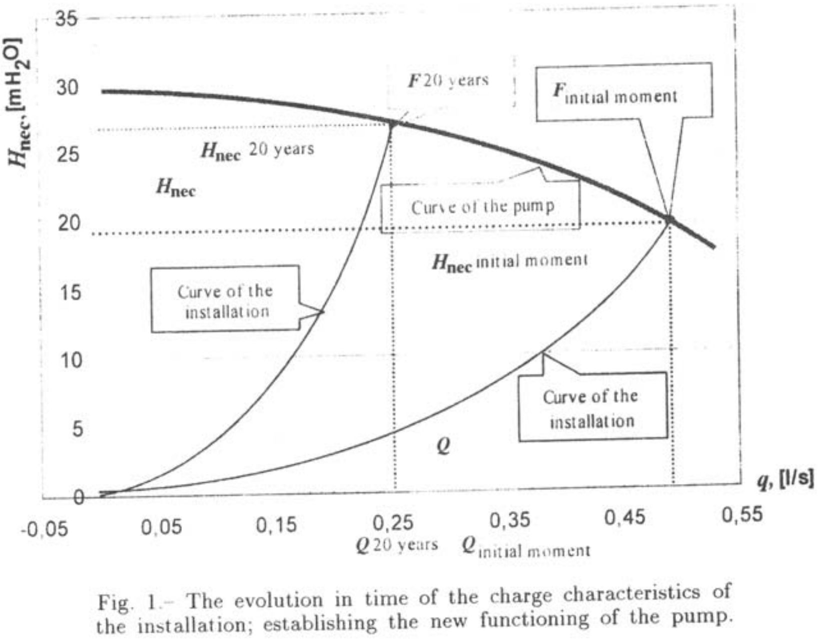


Fig. 1.– The evolution in time of the charge characteristics of the installation; establishing the new functioning of the pump.

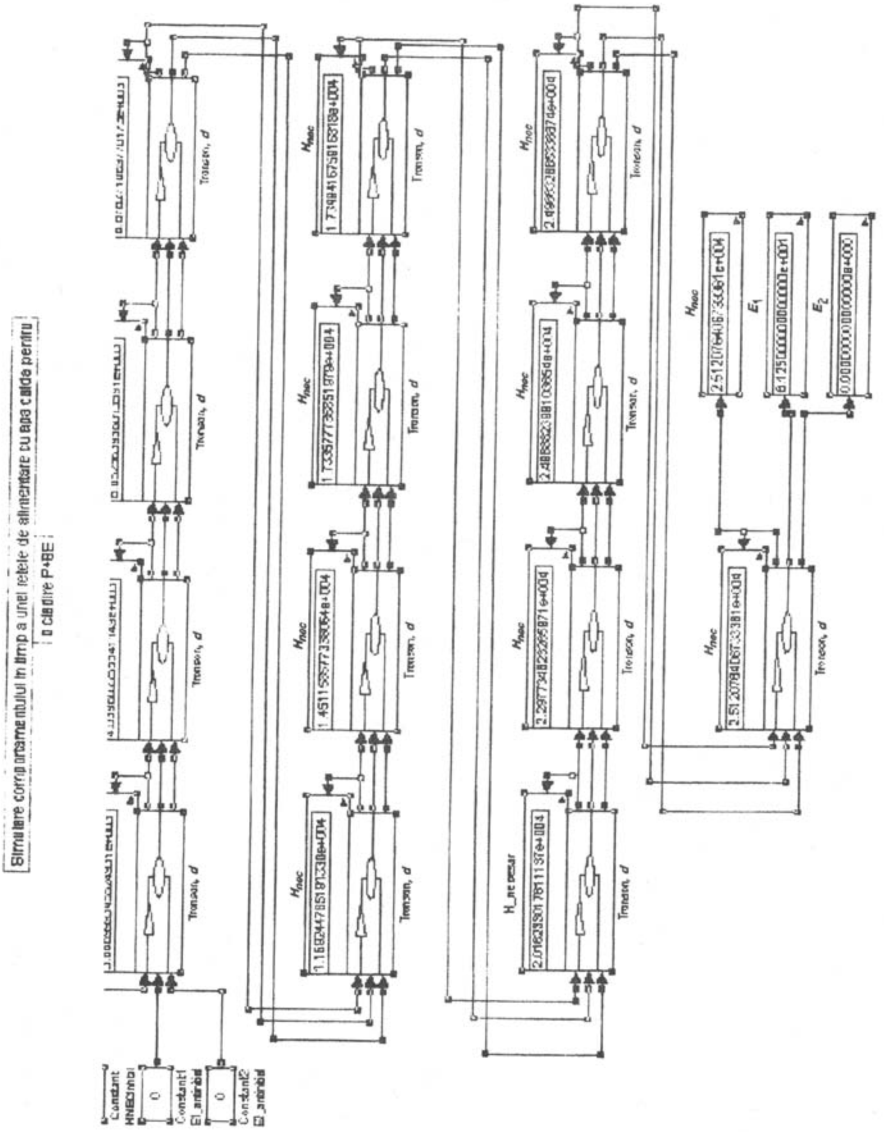

Fig. 2.- The model of simulation behaviour of the plumbing systems by steel at tartar effects plumbing for one building of logements with $P + 4E$.

b) Consequence of this behavior, the installation curve modifies and the functioning point of the installation moves on the characteristic curve, as shown in Fig. 2, with implications on the necessary water flow which can be reduced up to 50%, comparing with the initial flow to be provided. The "0" value for the corresponding last route flow justifies the fact that on this route, after the running time, it cannot be provided circulation flow without supplement the pump installation.

2. In the norms of design methods of the water supply installations it is made no difference between the performant/ not performant materials from the tartar deposit effect point of view.

3. According to the analyses made on the performances of the water treatment apparatus available on the market, these are mostly inefficient. Some of them could become, in wrong exploitation conditions generators of the *legionella* development.

4. Consequently the design prescriptions should allow to prevent the tartar deposit effect through:

a) the obligation to include the efficient water treatment installations;

b) to include the tartar deposit effect method within the design procedure when the installation is not provided with water treatment system.

This can be made:

a) analytically, based by the optimal design programs, which considers this effect;

b) recommending differentiated calculation speed accordingly to the pipe material;

c) including an increasing pressure installation able to cumulate the continually pressure up charge of the initial necessary pressure due to the tartar deposit effect.

*Received, May 20, 2004*

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REFERENCES

1. Nenițescu C.D., *Chimie generală*. Ed. Did. şi Pedag., Bucureşti, 1972.

2. Ayerle H., *XNET2-Metodical Design of Local Area Network in Buildings*. CAAD futures 1991 Proc., Zürich, 1991.

3. Cotorobai V., *Consideraţii privind introducerea unor noi criterii de calcul şi evaluare a performanţelor instalaţiei tehnico-sanitare*. Ph. D. Diss., Techn. Univ. "Gh. Asachi", Jassy, 2000.

4. Griffin D.M.Jr, *Carbon Dioxide Equilibrium and their Application*. Louisiana Techn. University, USA, 1982.

5. Hamy J.P., *Pathologies et traitements curatifs des installations d'E.C.S.* Chaud-Froid-Plomberie, *568* (1995).

6. Mure P., *L'efficacité des systèmes antitartre mise à l'épreuve*. Chaud-Froid-Plomberie, *594* (1997).

## O METODĂ DE SIMULARE A EFECTULUI DEPOZITELOR DE TARTRU ASUPRA PERFORMANŢELOR SISTEMULUI DE „INSTALAŢIE SANITARĂ"

(Rezumat)

In procesul de exploatare a instalaţiilor interioare de alimentare cu apă (şi in special a celor de alimentare cu apă caldă), la realizarea cărora s-au utilizat conducte de oţel (zincat) sau materiale plastice polare se constată o reducere a capacităţii de deservire a consumatorilor cei mai dezavantajaţi in perioadele varfurilor de consum. Disfuncţionalitatea se datorează efectului depunerilor de tartru pe pereţii conductelor. Acestea au drept consecinţă creşterea pierderilor de presiune liniare şi respectiv diminuarea presiunii de deservire a consumatorilor.

Se prezintă modelul de simulare a efectului depunerilor de tartru asupra comportamentului in timp al instalaţiei construit cu ajutorul funcţiilor specializate din toolboxul Symulinc. Exploatarea modelului permite formularea unor propuneri pentru considerarea efectului depunerilor de tartru in metoda standardizată de dimensionare a instalaţiilor.