Modelling of Depollution Process in an Aquifer through Injection and Extraction Wells and Treatment of Polluted Water at the Ground Surface

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Environmental protection is a very important component of the lasting development concept. The care of giving the future generations enough resources to a growing society should concern the quality as well as the quantity of our actions. For this reason the protection of the ground water resources should be carefully handled. Because of the slow flow rate of the ground water, the effects of a present pollution could have repercussions on the environment for tenths of years from now. Unearthing the pollution sources and using the adequate de-pollution procedures could protect efficiently the tapping of ground water. In this paper is presented the case of ground water pollution with phosphates and the aquifer de-pollution procedure through injection and extraction wells. Also there is presented a single casting treatment plant that uses the ion exchange procedure.

Key words: diffusion, dispersion, ion exchanger (ion exchange plant), phosphates, underground water pollution, degradation, resin, and infiltration

The phosphorus could be found in natural water as inorganic soluble phosphorus (ortho-phosphates: PO_4^{3-}, $H_2PO_4^-$, HPO_4^{2-}) which is directly assimilated by the plants and as organic phosphorus. The phosphates (PO_4^{3-}) represent the form in which the phosphorus is found in the most cases. The secondary phosphates ($CaHPO_4$) are less soluble in water and the primary phosphates ($Ca(H_2PO_4)_2$) are soluble in water and easy assimilated [2].

Concentration of phosphates bigger than 0.1 mg/dm^3 from underground water makes impossible to use it without a previous treatment [5].

Some of the ground water pollution reasons with phosphates are: the lack of centralized sewage systems in the rural area, the damage of the draining pipes, the conveyer pipes and the reservoirs from the fertilizers and wash detergents production plants.

A diffusive source of phosphates pollution is the unrational usage of fertilizers on agricultural terrains that are preceded by precipitations which facilitate the quick infiltration in the aquifer.

Because of the diffusion-dispersion processes, small speed displace of the underground water flow, will take place a scattering of the polluted substance followed by concentration decrease [3].

Taking rapid measures of aquifer de-pollution affected by the natural damages will drive to avoiding the scattering of the polluted substance on big surfaces, a shortage of the de-pollution period and a reduction of the expenses [4].

Calculation model of pollutants transport in underground water

Diffusive – disperse transport of pollutants in underground water, in bi-dimensional model, takes place according to the first law of Fick:

$$\vec{q} = -n_e \cdot \overset{\Rightarrow}{D} \cdot \nabla C \qquad (1)$$

$$D_L = \alpha_L \cdot v_i + D_{dif} \text{ and } D_T = \alpha_T \cdot v_i + D_{dif},\ D_L > D_T \qquad (2)$$

Pollutes which arrive in underground water are partialy absorbed by the solid matter.

$$r_a = (1 - n_e) \cdot \rho_s \cdot k_d \frac{\partial C}{\partial t} \qquad (3)$$

Once in underground water, pollutants are chemicaly and biologicaly degraded:

$$r_d = \lambda \cdot m_t \qquad (4)$$

$$m_t = m_p + m_a = n_e \cdot C + (1 - n_e) \cdot \rho_s \cdot k_d \cdot C \qquad (5)$$

The degradation rate becomes:

$$r_d = \lambda \cdot [n_e \cdot C + (1 - n_e) \cdot \rho_s \cdot k_d \cdot C] = \lambda \cdot n_e \cdot R \cdot C \qquad (6)$$

$$R = 1 + \frac{1 - n_e}{n_e} \rho_s \cdot K_d \qquad (7)$$

Transport equation, which is used by the ASMWIN program has the expression:

$$\frac{\partial C}{\partial t} + \frac{1}{R} \nabla(\vec{v} \cdot C) - \frac{1}{R} \nabla\left(\overset{\Rightarrow}{D} \cdot \nabla C\right) - \lambda \cdot C = 0 \qquad (8)$$

By solving the transport equation we shall determine the function $C = f(x,y,t)$, through a numerical method based on stochastic walk method “Random Walk”. This is a statistical method that has at base the transport equation for particles of pollutant. The pollutant particles are moving in trajectories dictated by convective motion and the diffusion-dispersion effect is simulated on statistical way by generating trajectories for each particle in successive time periods.

Statistic generation of the trajectories for each particle has at base the relations:

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$$x_p(0) = x_0, \quad y_p(0) = y_0$$

$$x_p(t+\Delta t) = x_p(t) + u_x^{'}\Delta t + Z\sqrt{2D_L \Delta t}\,\frac{u_x}{u} - Z^{'}\sqrt{2D_T \Delta t}\,\frac{u_y}{u} \quad (9)$$

$$y_p(t+\Delta t) = y_p(t) + u_y^{'}\Delta t + Z\sqrt{2D_T \Delta t}\,\frac{u_x}{u} + Z^{'}\sqrt{2D_L \Delta t}\,\frac{u_x}{u}$$

$$u_x^{'} = u_x + \frac{\partial D_{xx}}{\partial x} + \frac{\partial D_{xy}}{\partial y} \quad (10)$$

$$u_y^{'} = u_y + \frac{\partial D_{yx}}{\partial x} + \frac{\partial D_{yy}}{\partial y}$$

For each particle that moves on the trajectories described before, the ASM program will calculate the concentration of pollutant from underground water at different periods of time. The result depends on the discretizate domain, the number of particles chosen to simulate the injected mass of pollutant in the ground water and on the initial conditions.

Numeric example

In the numerical example was considered:

-aquifer with free level, which has the coefficient of hydraulic conductivity k =0.001 m/s;

- aquifer thickness *H=15* m; flow of extraction and injection well *Q*=17 L/s; hydraulic gradient I=1‰ (fig. 1);

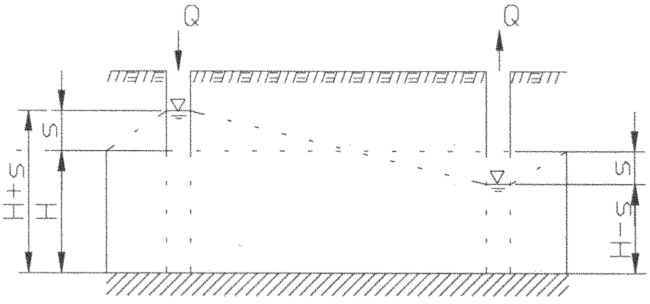

Fig. 1 . Vertical section through aquifer

- influence radius of the drilling R=120 m.

The phosphates concentration in the underground water before pollution was considered c=0,05 mg/dm^3. Evolution of the polluted front was simulated with an instant injection (30 kg) with ASM 5.0 program, which used the finite difference method for solving the motion equation and Random-Walk method for transport equation [6]. Dimensions in plan of polluted front, before beginning the de-pollution were considerated L=800 m; l=200 m (fig. 2).

The domain has a rectangular form with the dimension 1500 . 500 m (fig. 2).

Position of the injection-extraction wellwas analyzed in two ways:

- at the downstream limit an extraction well and a injection well at upstream limit figure 3.

- two extraction wells into polluted front and two-injection wells upstream limit of this figure 4.

In first way the domain was been discretizated in rectangular elements (15 on horizontal direction and 7 on vertical direction). In the second way, the domain has been discretizated in rectangular elements also, with 30 on the horizontal direction and 10 on vertical direction.

Running the ASM5.0 program with this data we obtained the concentration of phosphates in extraction well and the time for pumping the water at ground surface. In the first way the maximum concentration has the value c_{max}= 0.15 mg/dm^3 (fig. 5) and the time necessary for pumping the water 400 days. In the second way c_{max}=0.35 mg/dm^3 in Fc$_1$ well and c_{max}=0.25 mg/dm^3 in Fc$_2$ well (fig. 6) and the time necessary for pumping the water 200 days.

Water phosphates elimination through ion exchange procedure

The proposed plant for de-pollution of under-ground water uses the ions exchange procedure. The ions exchange mass is formed by resins (synthesis substances)

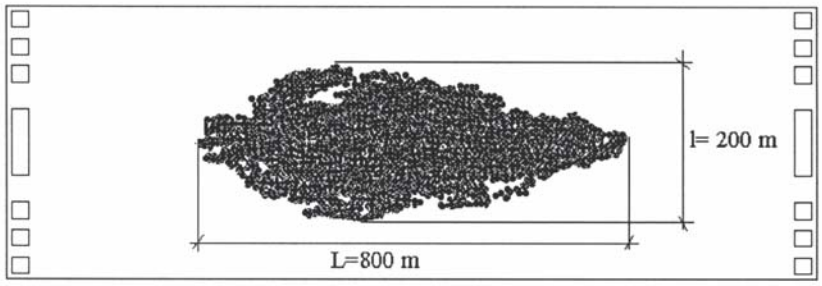

Fig. 2. Polluted front

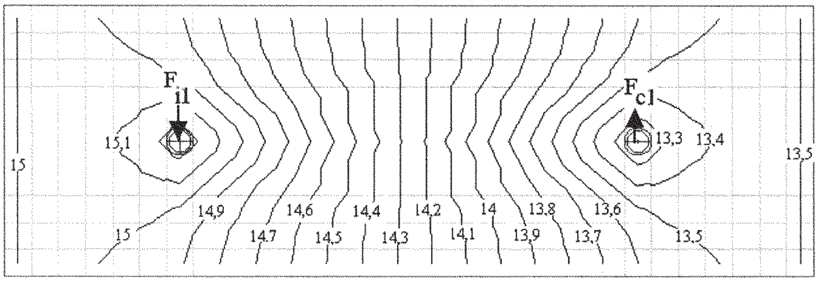

Fig. 3. Injection and extraction wells positions

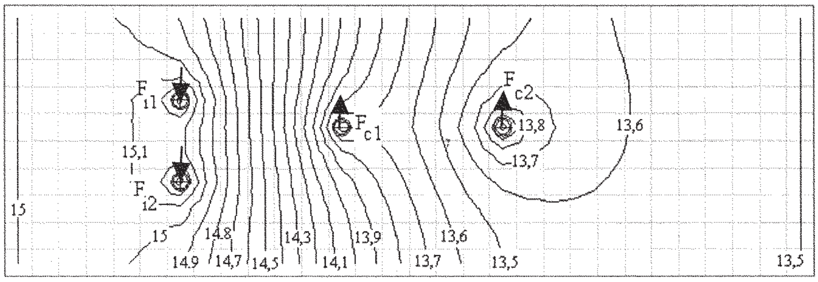

Fig. 4. Position of two injection wells and two extraction wells

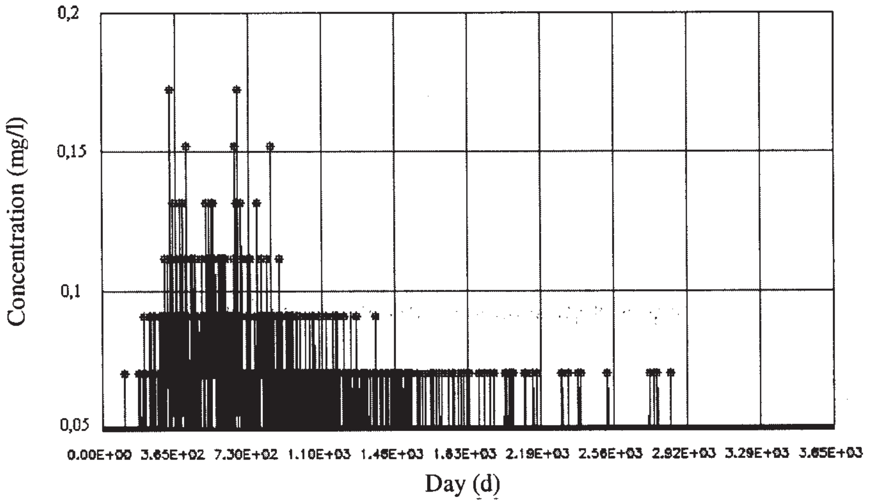

Fig. 5. Evolution of the phosphates concentration in extraction well (F_{c1})

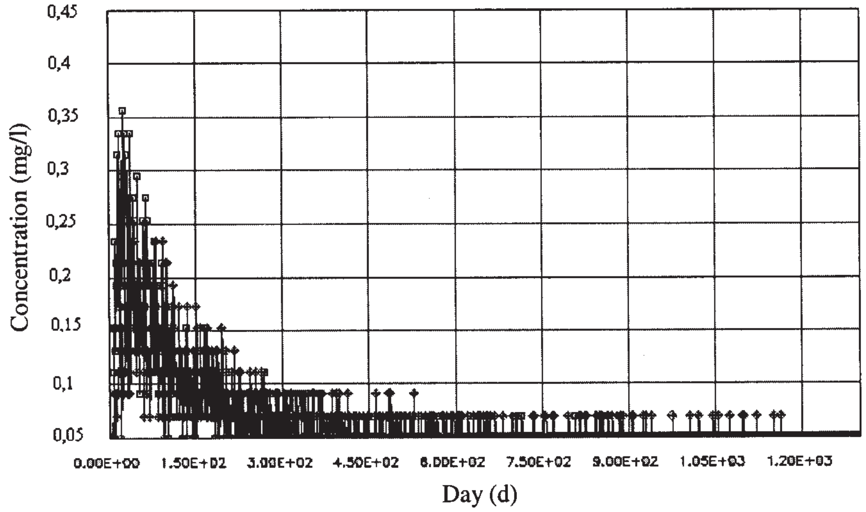

Fig. 6. Concentration phosphates evolution in extraction well (□ F_{c1},◇F_{c2})

which retained the PO_4^{3-} ions from pumped underground water and released the hydroxyl ions.

In this manner, will be realised a continuous removal of the ions and will be avoided the equilibration of the phosphates concentration from crude water and from ions exchange mass.

The exchange process is finished when the resin is stung and the water quality does not correspond. Regeneration will take place, through removal process of the PO_4^{3-} from crude water with hydroxyl (HO^-) from resin structure, as a result of contact with a solution that contain exchange ions in a big concentration. The plant use for de-pollution has flow direction from up to down, and the regeneration solution down to up. Ions exchange process is a irreversible process and kinetic efficiency is big. In this manner inferior layer will be regenerated and in this way phosphates ions will be removed.

Ion exchange plant is composed from a reactor (filter) and a vertical cylinder (fig. 7) [7]. Into reactor it is a mass of resin and drainage systems (plaque with stainer screen) to the superior and inferior part. On the resin layer exist a free space necessary for resin expanding.

Drainage system must resist to action of crude water and regenerated solution; to assure an uniform distribution of water flow that is treated; to stop mass resin expanding. Between resin mass and drainage system from the inferior part, there is a granulated layer that has 20 cm by inert material. Ion exchange process will go on according to the following reaction:

$$R\text{-}A^{\pm} + B^{\pm} \Leftrightarrow R\text{-}B^{\pm} + A^{\pm}$$

Reactor functionality has a cyclic character and contains the following operations: removal (ions of phosphates are changed with hydroxyl (HO^-) from crude water); regeneration, wash and loasening [1].

In the regeneration process ions exchange mass will get back the property after some special treatments. This operation takes place with excess of the regenerate electrolyte for a complete substitution of the ions. Regeneration time is 25-45 min and the velocity of the regeneration solution through resin mass is 2-5 m/h.

Regeneration scheme in counter flow is present in figure 8.

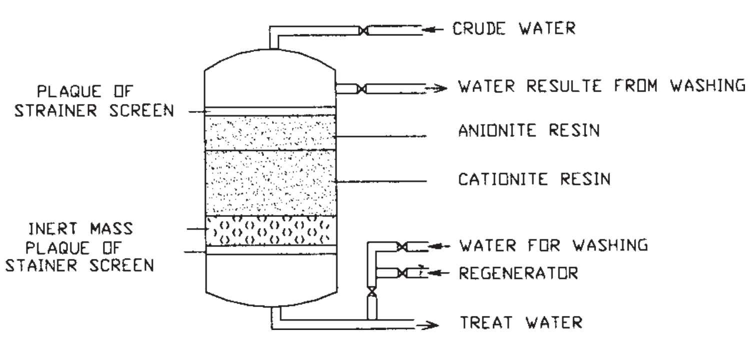

Fig. 7. Reactor

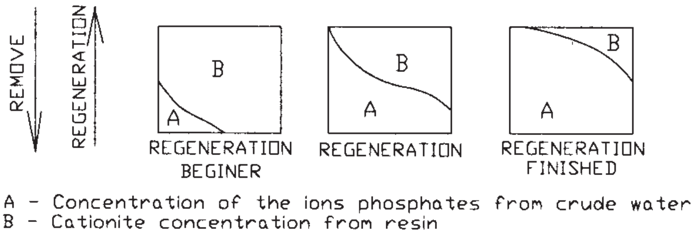

Fig. 8. Regeneration scheme in counter flow

The regeneration reagent will be injection in resin mass down to up.

Through washing operation have place eliminate of regeneration solution and the secondary produces that has formatted in regeneration time. This operation take place in the same sense with the regene-ration and will be finish when the evacuated water will have not regenerators. It is utilised the unique wash process, which need 30 min and the velocity of water through resin mass is 4…10 m/h. In functionality cycle is utilised 3…5 m^3/h . m^3 resin. Loosening operation will lead at expanding of granular resin mass.

This operation will be realised by injected treatment water (3...6 dm^3/s . m^2 resin), 10…20 min until the water will be clear. In this manner impurities contained by the crude water and the regeneration solution will be eliminate after passing the resin mass. In the same time will be stop the cementer of resin and the crude water and regeneration solution will have a good contact with the resin.

For a hydraulic calculus of the filter there were used the following parameters:

-crude water flow (from two drillings) Q=122 m^3/h;

-exchange capacity of the macro porous resin for cationite strongly acid $C_C=1.8\frac{val}{dm^3}\cdot\frac{m^3\text{water}}{m^3 re\sin}$;

-exchange capacity of the macro porous resin for weak base anionite $C_A=1.4\frac{val}{dm^3}\cdot\frac{m^3\text{water}}{m^3 re\sin}$;

-regenerator type used for cationite resin is sulphuric-acid with the regeneration level $150\frac{kg\ regenerator}{m^3 resin}$;

-regenerator type used for anionite resin is hydroxide sodium with regeneration level $80\frac{kg\ regenerator}{m^3 re\sin}$;

-total volume of cationite resin from filter V_c;

-total volume of the resin from filter V_a,

-surface of the resin mass S and the height of this;

-total height of the filter h_t which will use the relation (11- 15);

-regeneration time t_r=1h;

-regeneration velocity v_r=3 m/h;

-washing time t_s=30 min;

-washing velocity v_s=6 m/s;

-flow of washing solution q_s=1.12 m^3/h;

-velocity of crude water in resin mass v=20 m/h;

-free space up to resin mass until plaque with strainers screen h_c=40 cm.

$$V_C=\frac{\alpha\cdot Q\cdot t\cdot dT}{C} \tag{11}$$

$$V_A=\frac{Q\cdot t\cdot dp}{C_A} \tag{12}$$

$$S=\frac{Q}{v} \tag{13}$$

$$h=\frac{4\cdot V_{c1}}{\pi\cdot D^2} \tag{14}$$

$$h_t=h+h_e+2h_d+h_i+2h_g \tag{15}$$

Using these relations we shall obtain:

-total surface of the resin mass 6.1 m^2;

-volume of cationite resin 0.74 m^3 from a filter;

-volume of anionite resin 0.91 m^3 from a filter;

-height of resin layer 0.80 m (0.36 m cationite resin, 0.44 anionite resin);

-total height of filter 2.05 m;

-only in conditions when there were choosen three filters with diameter D=1.60 m.

Treatment of water with ions exchange is a complex process that needs a continuous monitoring realized by a computer.

Treatment plants with ions exchange exist in: Tournai-Belgium (open filters with cationites; loosening velocity 6.12 m/h, regenerator velocity 2…3 m/h; washing water velocity 5…10 m/h); Belleville-France (three reactors with a total flow 445 m^3/h); Narcea Oviedo-Spain (two reactors with a total flow 100 m^3/h); Mannheim – Germany (total flow 210 m^3/h).

Conclusions

Depollution of aquifers by phosphates requires a complex plant. All the processes from the reactor are strictly supervised and managed by the process computer. The efficient of the exchange ions procedure using macro porous resins is extremely large. The advantage of regeneration in counter flow is a smaller reagents consume compared with the flow procedure.

Time for pumping the water of ground surface, treatment of water with ions exchange and re-injection the water up-stream of the pollution front it was estimated at 400 days when it is used an injection well and an extraction well. In case there are used two extraction wells into the pollution front and two injection wells up-stream of these then there are necessary 200 days. Without injection wells, which create a bigger hydraulic gradient the time necessary for de-pollution and the expenses will be high.

Notes

$\vec{q}$ – specific flux of polluted mass which pass in time unit through surface unit;
n_e – effective porosity of the porous medium;
C – pollutant concentration definedlike mass of substance in unity of volume;
D– tensor of the diffusion-dispersion coefficient with the components:
D_L,, D_T – hydrodynamic coefficients of longitudinal dispersion;
α_L, α_T – longitudinal and transversal dynamic dispersions;
v_i – linear medium velocity of the underground water in direction of flow i;
D_{dif} – coefficient of molecular diffusion;
r_a – adsorption rate of the pollutant;
ρ_s – density of solid phase;
k_d – adsorption coefficient;

r_d – rate of degradation;

λ – coefficient of chemical and biological degradation;

m_t – total mass of the pollutant contained by the volume unit of porous medium:

m_p, m_p – mass of pollutant from liquid respective phase, adsorbed by solid phase

R – delay reactive coefficient.

u_x , u_y – components of movement velocity on two directions x,y;

Z, Z' – statistic coefficients of repartition.

R – ions from crude water, except phosphates;

A - PO_4^{3-} from crude water;

B – hydroxyl concentration from resin mass with phosphates from taken out crude water.

$\alpha = 1.5$, coefficient depending on supplementary volume for washing resin;

t – time for removal phase 6.25h;

dT – total hardness of crude water (3.5 mval/dm^3);

dT – permanent hardness of crude water (5 mval/dm^3);

V_{C1}, V_{A1} – volume of cationit, anionit resin from a filter;

h_g - hight between strainer screen plaque and extremes of filter (0.25m).

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