MATHEMATICAL MODELLING OF BIOLOGICAL TREATMENT PROCESS IN THE SEWERAGE SYSTEM

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Majoritatea oamenilor consideră sistemul de canalizare doar un simplu sistem de transport al apei uzate. Totuşi, în sistemul de canalizare au loc procese biologice, chimice şi fizice prin care se modifică proprietăţile apei uzate în timp ce ajunge la staţia de epurare.

În această lucrare se prezintă rezultatele modelării proceselor de curgere a fluidelor polifazate prin reţeaua de canalizare în condiţii aerobe realizate prin introducerea de aer în mediul apos cu ajutorul unei instalaţii pneumatice de oxigenare.

Many people consider that the sewerage system is just a simple transport system for wastewater. Some biological, chemical and physical processes take place in the urban sewerage system. These processes modify wastewater characteristics during its transportation towards the treatment plant.

This paper shows the results of multiphase fluid flow inside the sewerage system, in aerobic conditions developed by introducing air in the aqueous medium by means of pneumatic oxygenation equipment

Keywords: sewerage system, mathematical modelling, aerobic transformation

1. Introduction

Modelling of physical, chemical and biological processes, which take place in the sewerage system, is difficult to achieve because of the complexity of these processes.

Mathematical models which describe wastewater flow in the sewerage system are shown in the technical literature; these models use the following types of equations [1]:

- Equation of fluid flow inside the sewerage transportation pipe – derived from Navier-Stokes equation system, adapted to specific conditions;

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- Equation of organic matter dispersion from the aqueous medium into a permanent flow, having the reaction of matter damage;
- Dispersion equation with oxygen diffusion in the aqueous medium;
- Equation of activated sludge flocks dispersion, having the reaction of organic matter demand in the presence of oxygen;

Other types of models which describe the transformations of wastewater inside the sewerage system are biological defined models [2]. The concept of microbial transformations inside the sewerage system is based on the description of the activated sludge model, i.e. biomass increase and substrate use [3]. Therefore, some relations were set up between microbial transformations which take place in the sewerage system and in a successive treatment in the treatment plant [4].

The model drawn up in the present paper is a theoretical foundation model which contains relations between different parameters, as well as the concept related to the causal mechanism which founds theoretically this correlation.

This model is based on the analysis of physico-chemical-biologic phenomena which take place in the process of multiphase fluid flow inside the sewerage system.

The model novelty consists in introducing the kL term in a mathematical equation in order to describe the flowing process considering the organic matter breaking down as a result of cellular metabolism, in the presence of oxygen, term which contains the influence of hydrodynamic factors and all the physical, chemical and biological processes.

2. Content of work

The sewerage system has a great importance due to the following aspects:

- sewerage system length is great – over 5 km – and it does not represent, excepting the transportation, a utility;
- organic load has been very much increased lately (over three times) especially as a result of water demand increase;
- the capacity of wastewater treatment plants will be overweighed and they will not be able to cover most of the organic load; this fact will lead to the use of certain solutions which ease their load;
- it is unusual that a period of 6÷10 hours, needed to run through the sewerage system, not to be used for organic load decrease in order to ease the treatment plant load;
- the use of sewerage system as a ”pre-treatment plant” will lead to beneficial effects for wastewater treatment.

Physical, chemical and biological processes take place in the sewerage system and modify the properties of wastewater while it is carried to the treatment plant.

Physical processes are specific for problems related to applied and theoretical hydraulics. Therefore, this flow is a result of the transformation of positional potential energy in kinetic energy. The aqueous medium flows with a speed of o.4...0.9 m/s, due to channel slope of 2…5 $^{0}/_{00}$; it is to be mentioned that the flowing speed may rise up to 1.6 m/s if there are great flows. The sewerage system must be designed and executed so as to be able to ensure the suspended transport of all the solid particles thrown in the sewage.

Chemical processes which take place in the sewerage system are those specific for acid water neutralization by alkaline water, precipitation and coagulation. As a result of these reactions, in the sewerage system, neutral water which contains certain particles resulted by coagulation and flocculation of mineral or organic particles can be obtained.

Biological processes are specific for the stage of damaging carbon or nitrogen based organic matter, as a result of biochemical reactions which take place between these elements, dispersed in the aqueous medium and aerobic or anaerobic bacteria existing in water. These reactions result in releases of carbon dioxide, hydrogen sulfide and other compounds of metabolic reactions, in the gaseous medium.

We mention that all these processes, of hydraulic flow as well as chemical and biochemical ones have a continuous character and they depend on time. Parameters, both the hydrodynamic ones and those with a different nature depend on time because they vary continuously in time and space. *Inside the sewerage system, the flow does not ever end, but it modifies its flow and load*.

Anaerobic conditions occur in the sewerage system because the transfer of oxygen trough the free surface of wastewater from the system is too weak to create an anaerobic medium in the water mass. In anaerobic conditions, the organic matter is decomposed by hydrogen sulfide, methane and carbon dioxide formation. These gasses have an unpleasant smell and they are very hazardous for system operators and sewerage system due to corrosion process occurrence.

The method proposed is to develop aerobic conditions by introducing air in the aqueous medium by means of pneumatic equipment for oxygenation. The development of anaerobic conditions for hydrogen sulfide and methane presence is avoided in such a manner. An injection of activated sludge existing in excess in the physical-chemical-biological treatment plant is made at the end of the pipe system. If aerobic conditions are present, the supplementary activated sludge will lead to organic matter damage and ease the load of the treatment plant from downstream.

Process modelling and simulation may be developed by considering the process of activated sludge, biomass increase and use of a substrate similar to the technology from the biological stage of the treatment plant. Therefore, the sewerage system may be considered as a treatment plant, from the physical-chemical-biological processes point of view.

Multiphase fluid flow in the sewerage network represents the following:

- transmission of inorganic and organic solid particles by the aqueous medium;
- organic matter damage during transportation, due to aerobic processes which take place between bacteria from the sludge introduced and the air blown in; the basic condition for these reactions development is that of nutrient presence in the aqueous medium; these nutrients are necessary for the process – nitrogen and phosphorus in a ratio requested by the process;
- chemical and biochemical transformations of sulphur based compounds;
- gas transfer from the gaseous medium above the wastewater free-level – especially of oxygen from the gas blanket.

The basic problem is to establish a correct dimensioning of the sewerage system so as the solid suspended matters not to be settled on the channel bottom, forming deposits which are hard to be carried along. Modelling of flowing process will not consider this hypothesis relevant for a wrong operation.

Processes from the sewage pipe mainly differ from one another due to the values of kinetic constants. The rate of heterotrophic biomass increase and organic substrate hydrolysis may be maintained in aerobic conditions. We mention that in modelling the complex process which takes place in the pipage of the organic matters, the values of activated sludge concentration are not similar to those from the activated sludge process. This method may be applied continuously or when it is necessary to discharge high amounts of organic matters, values at which the treatment plant could be outstepped.

Organic matter dispersion and damage in the aerobic medium is the main phenomenon for modelling the processes of multiphase fluid flow inside the sewerage system. These are described by the following equation [1]:

$$\frac{\partial L}{\partial t}+\frac{\partial}{\partial x}(\overline{u}L)+\frac{\partial}{\partial y}(\overline{v}L)+\frac{\partial}{\partial z}(\overline{w}L)=\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial L}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial L}{\partial y}\right)+$$
$$+\frac{\partial}{\partial z}\left(\varepsilon_z\frac{\partial L}{\partial z}\right)+D_m\left(\frac{\partial^2 L}{\partial x^2}+\frac{\partial^2 L}{\partial y^2}+\frac{\partial^2 L}{\partial z^2}\right)+S(x,y,z,t), \quad (1)$$

Where:

- L – concentration of organic matter from water mass, mg/l;
- u, v, w – values of components for spatial flow speed, m/s;
- ε_x, ε_y, ε_z – longitudinal, transversal dispersion coefficients and on the vertical axis of the flow, respectively, m^2/s;
- D_m – molecular diffusion constant of oxygen in water mass – appears in this equation due to molecular diffusion over which dispersion is superposed, m^2/s;
- S(x,y,z,t) – demand or supply function. The term source/demand is that which considers containing all the physical, chemical phenomena and those related to the biochemical kinetics in the complex process of organic matter mineralization. This term will consider the organic matter demand and this will be accepted within a model of the type KL, $-KL^2$, $-KL^n$ i.e. or as a polynomial function – $(KL + AL^2 + BL^3 + ...)$.

A complete solution of this equation, at which equations of movement and continuity have to be added up, is impossible to obtain because dispersion coefficients depend on the flowing regime, on the nature, shape and size of dispersed particles, as well as on physical characteristics of media. We use simplified models for this reason.

The following hypotheses are drawn up for modelling of multiphase fluid flow inside the sewerage system:

- Unidirectional flow inside the sewerage system;
- The flow develops with a free area at atmospheric pressure, inside the pipe;
- The flowing regime is the permanent one;
- This regime is not stationary, due to different interactions which occur between the components of the multiphase medium.

If we consider the abovementioned hypotheses, equation (1) becomes:

$$\frac{\partial L}{\partial t}+\frac{\partial}{\partial x}(\overline{u}L)+\frac{\partial}{\partial y}(\overline{v}L)=\frac{\partial}{\partial x}\left(\varepsilon_x\frac{\partial L}{\partial x}\right)+\frac{\partial}{\partial y}\left(\varepsilon_y\frac{\partial L}{\partial y}\right)+$$
$$+D_m\left(\frac{\partial^2 L}{\partial x^2}+\frac{\partial^2 L}{\partial y^2}\right)-kL \quad (2)$$

Where u is the specific flow speed, v is a vertical component generated by introducing air in the liquid, in case of unidirectional movement of the aqueous medium which is identical for all the vertical planes. Air bubbles movement on the vertical axis of the flow generates the dispersed media carrying away into water towards the liquid free area.

The results of modelling the equation no. 2 are shown below, by means of FlexPDE program; this modeling is used for wastewater flow, having an organic load of 1 mg/l as relevant value (this may be any type of value: 100 mg/l, 1000 mg/l, 3500 mg/l i.e.) within a transportation pipe having a 5 km length and a diameter of 1.2m.

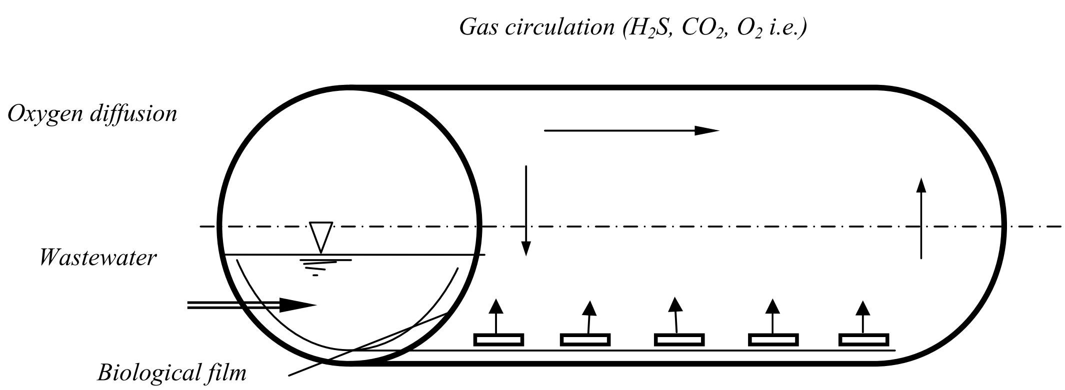

Fig. 1 Calculation diagram needed to establish the dispersion equation and organic matter demand.

Graphic representation is impossible to obtain because the sewage pipe is longer than its diameter. Its length is divided in sections of 350m, on which substrate concentration evolution is determined. For a higher length we will develop calculation on sections, taking into consideration the last value of the previous section and numerical integration, but we will maintain the multiphase fluid flow.

The results obtained for the distribution of organic matter concentration on a sewerage section of 350 m length, pipe diameter = 1.2m, for different values of flowing speed u, of a constant for demand speed k and of dispersion coefficients ε_x and ε_y are shown in Figs. 2÷6.

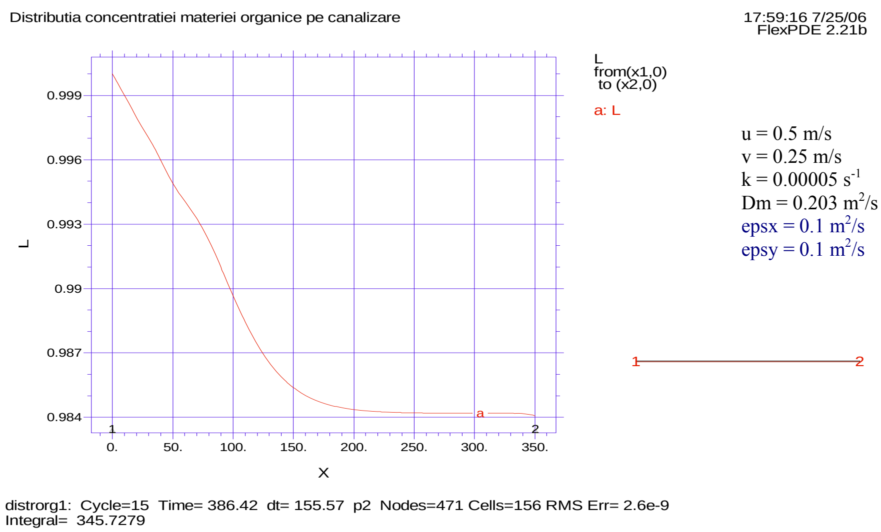

Fig. 2. Variation of organic matter on the whole length of the sewerage section for the study of interest. It is to be mentioned that the decrease of organic load too high, of 1.5% for the first 350m of pipe

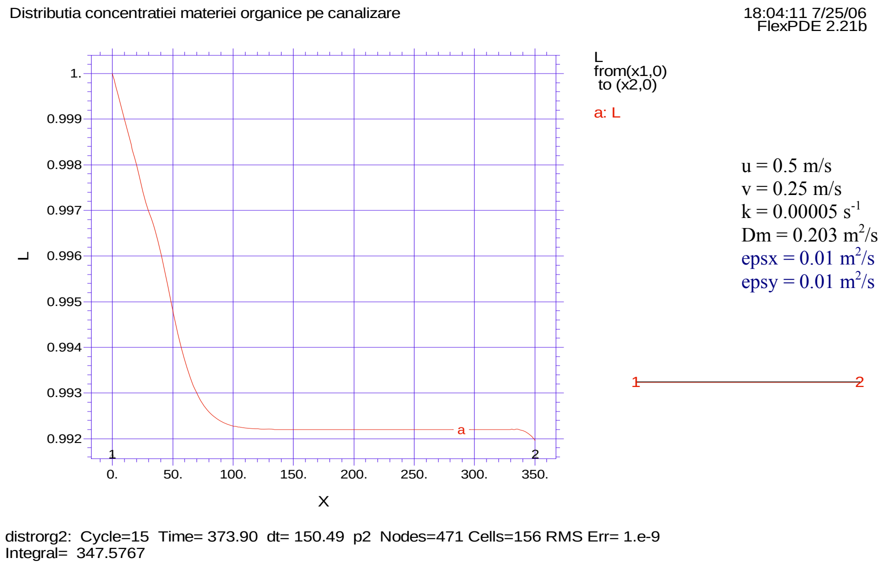

Fig.3 Variation of organic pollutant agent on 350 m pipe length when values of dispersion coefficients are lower. The decrease of organic load is of $8\%_0$, but it is present for the first 100 m of pipe

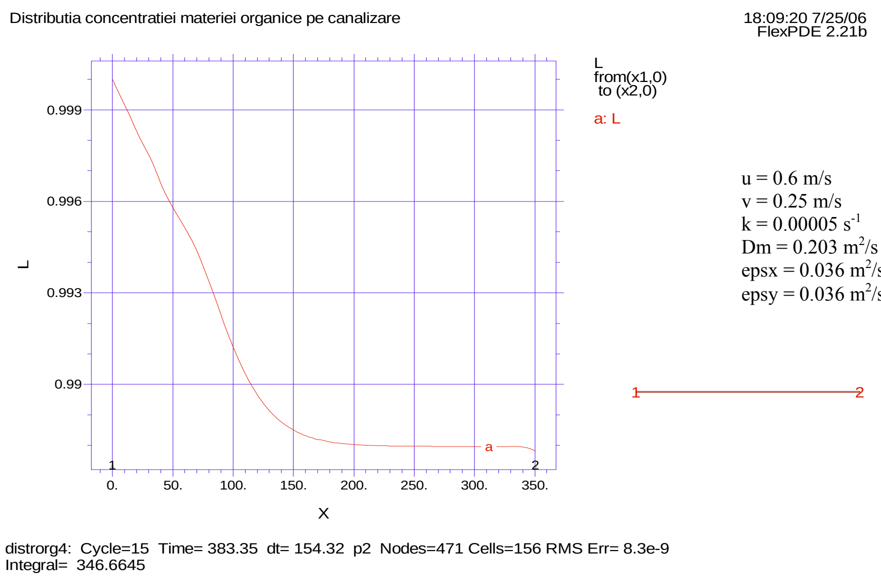

Fig. 4. Decrease of organic matter concentration values in water mass on the whole length of sewerage section, of 350 m. Organic load decrease is of 1.23%, but it is present for the first 150 m of pipe

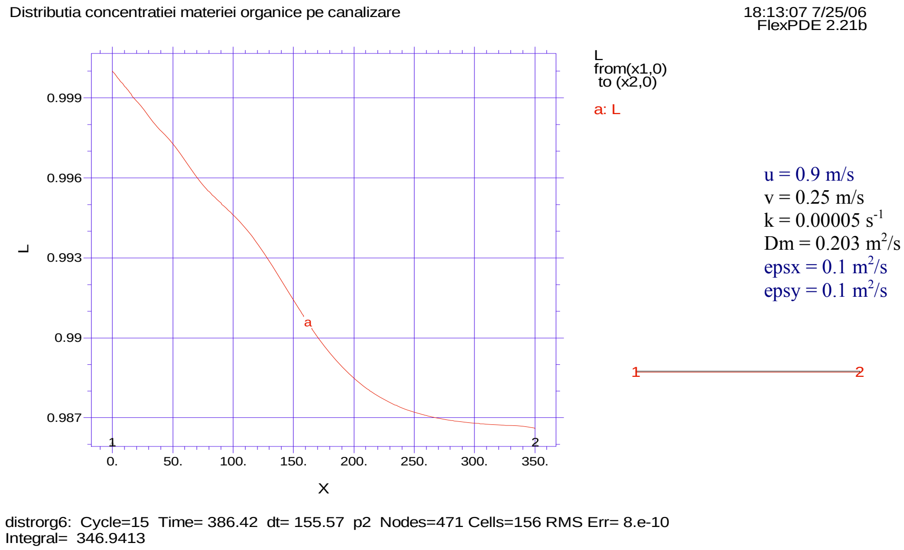

Fig. 5. The decrease of organic pollutant concentration is of 1.3%, but it is present for the first 250m, the last 100m are not implied in this process.

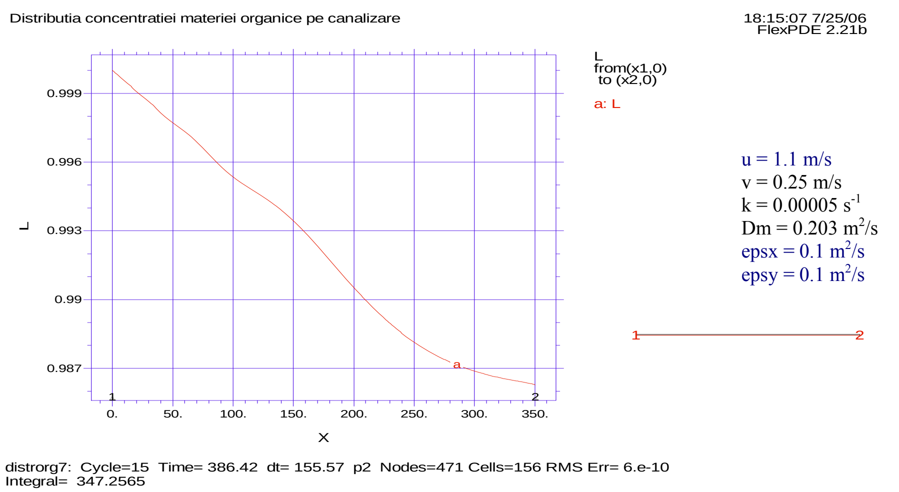

Fig. 6. Decrease of organic matter concentration values inside the wastewater sewerage system for a high speed, of 1.1m/s. The decrease of organic matter is of 1.375%. The contact between organic particles and activated sludge may be easily developed and their damage is present on the whole 350 m section, due to a high circulation speed, which may be reached only high fluid flows

We will consider sections of 350 m, taking into account the initial value of the previous section, in order to determine values of organic matter concentration on a 5 km pipe length. We will consider, for integration - the model which gives results similar to the real ones, a decrease of 1.28% on each section, respectively. Results obtained for modelling are taken into account; parameter values are as follows: u = 0.6m/s, v = 0.25m/s, constant of demand speed, k = 0.00005s^{-1},
Dm =0.203m^2/s, ε_x=0.036m^2/s and ε_y=0.036m^2/s.

{Gina1} TITLE ' Distribution of organic matter concentration inside the sewerage system'
VARIABLES: L
DEFINITIONS:
u=0.5 {water speed inside the pipe, m/s}
v=0.25 {ascension speed of the medium, m/s}
k=0.00005 {constant of demand speed, s^{-1}}
Dm=0.203 {constant of molecular diffusion, m^2/s}
epsx=0.10 {dispersion coefficient, m^2/s}
epsy=0.10 {dispersion coefficient, m^2/s}
x1=0 {area of admission into the pipe, m}
x2=350 {the length of pipe section, m}
y1=0 {bottom side of the pipe, m}
y2=1.2 {pipe diameter, m}
INITIAL VALUES: L=1
EQUATIONS:
*dt(L)+dx(u*L) +dy(v*L)=Dm*dxx(L)+Dm*dyy(L)+dx[epsx*dx(L)]+dy[epsy*dy(L)]-k*L*

Centralizer of data calculated for organic matter concentration along the length of wastewater pipage are shown in Table 1.

Table 1

Variation of organic matter concentration inside a sewage pipe having a length of 5 km

Run no.	Distance [m]	Concentration L [mg/l]
1	0	1.00000
2	350	0.98778
3	700	0.96950
4	1050	0.95766
5	1400	0.94596
6	1750	0.93440
7	2100	0.92298
8	2450	0.91170
9	2800	0.90056
10	3150	0.88955
11	3500	0.87868
12	3850	0.86794
13	4200	0.84282
14	4550	0.83252
15	4900	0.82234
Attenuation ratio of the organic matter		**17.8%**

The execution of this variation table for organic matter concentration considers maintaining the multiphase fluid flow. Therefore, wastewater discharge has not been made in the sewerage system, on this length. This section represents the output from the locality towards the treatment plant in which wastewater discharge from companies or individual farms will not be achieved. A decrease of about 18% of organic matter will be achieved on this length of sewage pipe, if the activated sludge is present in the wastewater and the values for physical-chemical-biological parameters are respected. It is obvious that this ratio is lower due to lowering of the activated sludge load.

3. Conclusions

The sewerage system may be used as a pre-treatment step for the treatment plant, in order to ease its load. not only as a transportation system for wastewater.

The method proposed is that of injecting in the sewer pipe, at its initial part, an amount of activated sludge which exists in excess in the wastewater treatment plant. A decrease of about 10…15% will be obtained and this eases the treatment plant load. Processes become aerobic inside the sewerage system and this leads to the removal of unpleasant smell generated by the organic matter anaerobic fermentation phenomena.

Modelling and simulation of aerobic damage process of organic matters existing in the water mass lead to results comparable with reality. Large amounts of activated sludge are obtained in the biological stage, in the treatment plant and at least a part of them is good to be used for injecting the sewerage system. Therefore, a decrease of wastewater organic load is achieved and this eases the processes from WWTP and the activated sludge separated in the clarifying tank will have another use. This is a method to increase the treatment efficiency of wastewater which enters in WWTP.

Future research activities may be focused on the following:

- influence of suspended particles and of resuspension process of sediments from the sewage, on biological processes which may take place in the sewerage system;
- efficiency study of sewage biofilm use in the pre-treatment processes from the sewerage system.

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