Archives of Hydro-Engineering and Environmental Mechanics
Vol. 49 (2002), No. 3, pp. 59–64

Interdependence of Hydraulic and Physico-chemical Phenomena in Water and Sewage Treatment Systems

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(Received August 21, 2002; revised October 12, 2002)

Abstract

Interdependence between hydraulic and technological phenomena is observed in every flow-through sewage treatment system, as well as tanks and other units in water treatment systems.

Flow conditions in sewage treatment plants **settling tanks** come down to keep velocity and turbulence parameters adequate as a type of suspended matter. Uniformity of flow distribution affects sedimentation effectiveness which results in the capacity of a unit, hence the ability to determine and shape flow distribution constitutes a basic skill for any practical operation.

In **biological units**, particularly in activated sludge chambers, the relationship between hydraulic phenomena and technological effectiveness is much more complex than in settling tanks. In these chambers it is necessary to ensure:full intermixing of sewage and activated sludge, an adequate range of velocities, homogeneity of oxygen and biomass concentrations, proper reaction time.

Uniform velocity distribution in rectangular chambers of units (biological chamber in sewage treatment plant; sedimentation and flocculation facilities; fresh, sour and bath water tanks; accelerators), as well as equal turbulence, could eliminate sludge banks, hydraulic clasps and penetrations. This ensures taking technological advantage of chamber capacity completely. Hydraulic resistance is minimized, which reduces energy consumption during the operating process.

Velocity distribution, homogeneity of mixture in a reactor as well as its hydraulic effectiveness characterize the level of taking advantage of project capacity for a given water or sewage treatment technology. These parameters are interdependent and very closely related, hence, searching for the most efficient solutions for chambers and channels, as well as mixing systems should be supported by detailed knowledge as to hydraulic behaviour of the investigated plants and facilities.

1. Introduction

Interdependence between hydraulic and technological phenomena is observed in every flow-through sewage treatment system, as well as tanks and other units within water treatment systems.

Flow conditions in sewage treatment plants settling tanks come down to keep velocity and turbulence parameters adequate for to the type of suspended matter (Elsner 1997). Uniformity of flow distribution affects sedimentation effectiveness, which influences the capacity of a unit. The ability to determine and shape the flow distribution, constitutes a basic skill in any practical operation.

The more uniform the flow distribution, the shorter the time of keeping sewage in settling tanks. This means that flow conditions directly influences the construction and maintenance costs of settling tanks.

In biological units, particularly in activated sludge chambers, the relationship between hydraulic phenomena and technological effectiveness is much more complex than in settling tanks. In these chambers it is necessary to ensure:

- full intermixing of sewage and activated sludge,
- adequate range of velocities,
- homogeneity of oxygen and biomass concentrations,
- correct time of reaction.

The hydraulically correct design of technological units may considerably improve their effectiveness. In particular:

- the whole capacity of a unit should be covered by moveing water,
- flow velocity should vary within the range resulting from the technological needs of a unit operation.

Uniform velocity distribution in rectangular chambers of units (biological chamber in sewage treatment plant; sedimentation and flocculation facilities; fresh, raw and bath water tanks; accelerators), as well as equal turbulence could eliminate sludge banks, hydraulic clasps and penetrations. This ensures the taking of technological advantage of the chamber capacity completely. Hydraulic resistance is minimised, which reduces energy consumption during operation.

2. Effectiveness of Units

A velocity distribution, homogeneity of mixture in a reactor, as well as its hydraulic effectiveness, characterise the level of taking advantage of a project capacity for a given water or sewage treatment technology. These parameters are interdependent and very closely related. Hence, searching for the most efficient solutions for chambers and channels, as well as mixing systems, should be supported by detailed knowledge as to the hydraulic behaviour of the investigated plants and facilities.

Reaching full technological effectiveness of flow-through facilities is extremely important since it affects the quantity of water supplied and quality of its treatment. This means higher reliability of water supply systems with lower energy consumption of their facilities. Sewage treatment is known generally as a highly energy consuming process. In case of unreasonable design, which is unfortunately common practice resulting from limited knowledge concerning the possibility of increasing the technical effectiveness of facilities; the energy consumed by a sewage treatment process grows considerably.

The projects of sewage and water treatment plant facilities consider mainly technological and constructional aspects and also recommend mechanical equipment and its energy supply scheme, describe arrangement of fittings and system of treatment process control. Consideration of hydraulic parameters of sewage and water treatment facilities, as well as fresh water tanks is most often reduced to calculation, but seldom verification, of the average velocity of flow-through chambers, channels and pipes. The detailed investigations on real objects are carried out incidentally and mostly when a unit does not reach its desired efficiency. Moreover, patents protect the most interesting and detailed methodology of investigations, as well as the desired technological solutions, which are being developed in foreign countries.

All these push researchers to develop their own investigations, mainly in laboratories, but also in pilot plants, and support them by adequate mathematical descriptions of hydrodynamic processes as well as the necessary measures. Polish bibliography covers only a couple of items dealing with this problem. In foreign literature the theory is hidden and only the final product is presented in the form of ready to use solutions, which comply very general data. Hence there is a need to investigate flow phenomena in chosen units of water and sewage treatment plants and evaluate them with respect to quantity and quality. The analysis of interrelation between technological and hydraulic processes is a background of such evaluation. The aim of investigations is to improve technical solutions, mainly geometry and the structure of units, as well as to ensure the best conditions of their operation.

3. Methods of Investigation

The considered facilities (in many cases with diphase flow) are very complex as regards their configuration and the structure of fluid inflow and outflow, and their influence on kinetic flow parameters is very strong. Hence, numerical methods, although they could be very effective, cannot here be applied in the form traditionally used for the complete flow equations of an unsteady spatial regime.

It is therefore suggested that use be made of an approximate method of a flow regime description enabling the finding of analytical or semi-analytical solutions, which be can then treated as a basis for the initial evaluation of hydraulic parameters of a unit. Such results help to prepare and carry out a reasonable hydraulic experiment, which will lead towards a desired solution. The following methods are used in this scope:

1. theory of transport of mass in diphase flows (with different fluid density or on a fluid – gas border) to evaluate effectiveness of flocculation and aeration processes,
2. evaluation of a mixing process in technological units,
3. use of a turbulent stream in a water half-space to evaluate a velocity field in the area in which units are supplied with fluid,
4. the influence of water allocation in a horizontal storey settling tank, on the sedimentation effect.

To achieve the desired effect it is most reasonable to use a method of hydraulic model investigation on a small, semi-technical or technical scale. Such investigations were carried out by the Author in:

- sewage treatment chambers,
- units of flocculation and sedimentation,
- fresh-water tanks,
- an accelerator,

and proved the thesis proposed in the title of the paper (Maciejewski 1999).

In the investigated units, physicochemical and biological as well as hydraulic phenomena take place. Only consideration of all of them ensures a reasonable final effect, which means high quality and economic efficiency. These two criteria ensure effectiveness of water and sewage treatment units, which serve both man and the environment directly.

Long lasting standing of water in the facilities mentioned worsens its quality parameters, therefore full exchange of water is necessary, as well as such water turbulence, which could eliminate sludge banks and zones of internal circulation. This means that, if possible, keeping time should be the same for all fluid molecules. For this it is important to ensure:

- technical parameters of a chamber, particularly its geometry, as well as a water inflow and outflow system,
- water motion parameters defined by a velocity field,
- mixing parameters of a chamber content.

The above criteria and parameters define hydrodynamics of chambers in the considered technical units. Fluid motion in chambers is here described on the basis of interrelation between fluid streams in unrestricted flow (Elsner 1987); in the phase of mixing without use of mechanical devices and also in the phase of mechanical and aeration equipment operation (Stręk 1987).

4. Velocity and Flow Field

A velocity field is the basic parameter describing motion in the investigated chambers (Maciejewski 1999). It defines a course of fluid currents in a flow area for a given water level. In most cases a velocity field is the determining factor for the choice of construction and technology for sewage and water treatment systems since it enables to determine:

- technical parameters and configuration of a chamber,
- arrangement of inlets and outlets,
- choice and arrangement of mechanical devices (mixing and aerating),
- type of construction,
- dead zones, as well as zones of intensive water exchange,
- zones of non-mixing flow.

A velocity distribution could be determined by means of:

- numerical method,
- experiment-based method, including measurements on model and real objects.

A numerical method necessitates the use of models based on three-dimensional flow equations. Since these equations are difficult to solve, the models are limited to a steady fluid motion with the following assumptions:

- for real flow conditions the models are worked out with considerable simplifications,
- results achieved using the complete flow equations are used only for very short segments of a regular, rectangular channel.

Investigations based on geometrically similar models enable the examination of qualitative and quantitative phenomena. They are useful for evaluation of the alternative solutions and searching for the optimal one. This is a kind of a model-based design with immediate evaluation of the proposed alternative. Reliability of the results is undoubtedly related to the model scale, experience of a researcher as well as to testing equipment. Hydrometric measurements enable the investigation of a velocity field in given flow conditions.

An experiment based method, which is undoubtedly more popular, consists in the use of measuring devices to determine direction and value of a velocity vector of every point of flow. The following equipment is used in this: a hot-wire anemometer, hydrometric current meter, Prandtl-Pitot head, laser anemometer. The main drawback of these methods is their high labour-consumption; moreover they need highly specialised personnel and can not always be applied in real objects.

5. Conclusions

Hydraulic problems appearing in a design, as well as in an operation phase of municipal systems is so complex and covers so wide a range of the detailed interests that is impossible to discuss all of them comprehensively in one paper. It is therefore reasonable to group problems according to their type and try to solve some of them effectively. It is also possible to classify problems according to the methods that could be applied in order to reach a certain scientific or practical goal.

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