CEEX Project, Module I, extern number: X2CO5/2006, intern number: 4205/2006

Theme:

HYDRO-GAS-DYNAMICS AND MASS TRANSFER IN FINE BUBBLE COLUMNS WITH APPLICATION IN ADVANCED ENVIRONMENTAL TECHNOLOGIES

Contract: CEEX X2CO5 / 18. 07. 2006
Contracting Authority: *AMTRANS Program – Society for research, designing and production of automation equipments and installations S.C. IPA S.A.*
Effecter: *INCDIE ICPE-CA Bucharest*
Project director: Prof. Dr. eng. Gheorghe BARAN

Program: CEEX – Excellency research
Project category: Module I – COMPLEX RESEARCH-DEVELOPMENT PROJECTS
Project type: P-CD
Project acronym: TEHNOMED

Development period of the project: *18. 07. 2006 – 20. 10. 2008*

Total value of the project: 1447500 lei
- from the budget: 1342800 lei
- co financing: 104700 lei

Partners involved in the project:
Project conductor / Partner 1: INCDIE ICPE-CA Bucureşti
Project director: Prof. Dr. eng. Gheorghe BARAN

Partner 2: Universitatea *POLITEHNICA* Bucureşti
Project manager: Sl. Dr. eng. Irina PINCOVSCHI

Partner 3: Universitatea TEHNICĂ DE CONSTRUCȚII Bucureşti
Project manager: Conf. Dr. eng. Mihnea SANDU

Partner 4: Universitatea POLITEHNICA Timişoara
Project manager: Prof. Dr. eng. Romeo SUSAN RESIGA

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Project manager: Drd. eng. Sidonia Mirela NICOLESCU

Partner 6: REGIA AUTONOMA DE GOSPODARIRE COMUNALA TARGOVISTE
Project manager: Conf. Dr. eng. Dorin STAICU

Thematic fields:
- Environmental technologies for observation, prevention, mitigation, adaptation and restoration of the natural and the man-made environment
- Technology assessment, verification and testing
- Energy efficiency and savings

Technological platform:
Water supply and sanitation

General objective:
The elaboration of a modern waste water treatment technology by advanced studies in hydro-gas-dynamic and mass transfer via fine bubbles columns, emitted by plaques with controllable porosity.

The accomplishment scheme of the project / time calendar:
2006 – **Stage I <u>Elaboration of the proposal for the optimization of mass transfer in free surface flow</u>**

Period: 18. 07. 2006 – 30. 11. 2006

Total value of the stage: 229 000 lei

2007 – **Stage II Theoretical and experimental researches concerning mass transfer for various aeration systems in stationary liquid and in flowing liquid**

Period: 01. 12. 2006 – 20. 10. 2007

Total value of the stage: 521 030 lei

2008 – **Stage III Experimentation and demonstration of the feasibility of the proposed technical and scientific solution**

Period: 21. 10. 2007 – 20. 10. 2008

Total value of the stage: 697 470 lei

The technical, social and economical impact
In wastewater treatment plants from UE the number of the fine bubbles generators (FBG) varies from 1 to 5 / square meter of basin. Therefore, in Romania are needed 300 pieces for a 60 × 6 m^2 basin; at the RAGC there are 6 of basins of this kind. There are no producers of FBG in Romania, only distributors, but at prohibitive prices (about 30 euro/piece, F 350 mm). Once manufactured the installation of such FBG in the basin represents a problem to be solved (in line, in chess, at ad.) so that their efficiency be maximal at a given flow rate, as well as the insurance of a service department. Issue the real necessity of setting up and developing specialized economic agents.
The new aeration system implementation will reduce the energetic costs in wastewater treatment plants with about 20 % and will assure wastewater treatment in accordance with the European standards, regarding technology and performance. Also, this system will assure environmental protection and quality thereby contributing to the human health. The proposed theme sustains a research network development with scientifically competence unique in our country in the field of waste waters aeration, improving the environmental factors being a priority objective for Romanian integration in EU.
The installations / stalls realized in the laboratory insure the logistics for some doctoral papers and the results will be verified in situ at RAGC Targoviste. Creating a web site, participating to national / international scientific events, will lead to an optimization in spreading the results among scientifically/technical community.

Objectives of first stage

Objective 1: Information concerning the existent modern aeration systems and the efficiency of gas-liquid mass transfer.

After consulting a number of 70 bibliographic references the result was a synthesis concerning the existent modern aeration systems. The air diffusion devices classification is maid depending on there sizes, shape and there construction material. The advantages and disadvantages of the use of these devices are exposed, as well as the causes of the eventually deteriorations and the reasons of utilization and development of these new technologies.

The optimization of the aeration systems, in order to establish the favourable operation conditions for reducing the consume of energy, needs the understanding of the mechanisms of hydrodynamic and mass transfer, of oxygen from air in to liquid phase, processes, which happens in aeration tanks and the concretization of these processes in mathematic models with solutions that describe as true as possible the real processes. This problem is yet in study and the efficiency of the aeration depending on air nozzles arrangement is in the stadium of empirical relations, for liquids at rest, which are confirmed in some experimental cases.

Objective 2: The study, selection and development, of the models for numeric simulation of hydro-gas- dynamics of bubbles and columns of bubbles in liquid.

Were studied 5 mathematic models concerning the hydro-gas-dynamics of air bubbles, in stationary liquid and in moving liquid, consulting a number of 16 bibliographic references, in order to select the adequate model, which are: the bi-fluid model, biphasic flow modelling, monophase fluid model, Zuber and Findlay model and Wallis model.

The studies for the numeric simulation models for biphasic flows characteristic to the aeration systems are presented. Were identified recent results from literature (from 17 bibliographic references), in order to establish the models which will be used forward in this project for numeric investigations. The pursuit purpose was to obtain similar results using two different mathematic models for biphasic flows. The solution presents interest for the disposal / arrangement of slide bubbles generators in the aeration tanks.

Objective 3: The characterization of the materials used in air diffusion.

A documentary study was realized, concerning the types of slide bubbles generators (from sintered glass, from ceramic material, from elastomer membranes) for aeration / oxygenation of residual waters, as well as information about the shape, dimensions, minimum and maximum flows of sir and pressure drops.

Also, are presented the theoretical bases for obtaining the sintered glass filters and the method for the experimental determination of pore diameter and of the permeability of sintered glass filters.

For realization of this objective is necessary to know the working parameters for the generators and to pick the generators which, with a minimum pressure drop, a low alimentation air flow and a big oxygenation capacity, give a good aeration for the waste waters.

Summarized of first stage

In the last years a big importance was given to the durable development of processes and technologies used in different domains of engineering. A waste water treatment plant can be an important risk source for the environment, human health and society, via the emissions in water, air and land. This risks can be reduces if the waste water treatment plant is designed and works in accord with the durable development and optimizing criterions.

It doesn't exist, yet, a general accepted methodology for evaluate the durable development of the waste water treatment plants or a set of criterions, which could became the base for thus an evaluation, in Romania or in UE. This is the reason why is very important to find new instruments which can be use in the evaluation of durable development of existing stations and of system management, as well as in developing of new ones. These studies can conduce at the improvement and promotion of those technologies and processes which connotes the smallest risk, have a big efficiency in proportion to the resources used and to the costs of there implementation. The modalities in which these objectives can be achieved are: mathematical modelling, the analysis of the process and of the optimizing, laboratory tests, pilot installations, for the innovative / new technologies, in situ experiments.

In the first chapter is analyzed the problem of oxygen transfer in the aeration tanks. In the present, the aeration is realized by tow methods: with mechanical or pneumatic devices, with the tendency of using preponderant the pneumatic ones. After the introduction of the aeration processes with active silt, were designed, tested, and developed many types of air diffusion devices, for increasing the beaming of oxygen solved in residual waters.

Preliminarily, the European and USA norms concerning the measuring of solved oxygen are presented, as well as examples of liquid phase circulation which is disadvantageous for the mass transfer.

In the second chapter is studied the modelling of biphasic flow in pipes, with slide between the liquid phase and the gaseous one strength on the phases distribution parameter and the slide velocity; this things depend on the type of flow, the dimension of the flow section (table 2.1). Three methods of flow are analyzed: equivalent monophase fluid, Zuber & Findlay and Wallis in order to select the one proper for the project. The chapter ends with the numeric simulation of the flow induced into the liquid from a tank by a bubbles column, axial injected.

The numeric experiments done in the 2006 phase by the P3 team shows:

- the conditions on the air entry sections, respectively the liquid free surface are essential for the accuracy of the numerical results
- for the injection of air via a porous plug must by determined the air volumetric function in water and the injection velocity
- at the free surface must by determined the air volumetric function equal with one, for obtaining the correct form of the free surface, respectively the velocities field corresponding to the recirculation of the gas in the tank.

In the third chapter was realized a documentary study concerning the types of slide bubbles generators (from sintered glass, ceramic material, elastomer membranes) for the aeration / oxygenation of the residual waters, as well as the world wide existing stadium, with the indication of the producers of waste water treatment equipments, also information about the shape, dimensions, the minimum and maximum air flows and pressure drops.

The pore's disposal in the structure is a characteristic of the apparent porosity of a ceramic porous material by a series of coefficients which set in bold type the influence of irregularities in shape and size of pores on the efficiency of the aeration process.

Also, are exposed the theoretical bases for obtaining the sintered glass filters and the method for the experimental determination of pore's diameter and of sintered glass filters permeability. To simplify the incipient fusion process and for doing the necessary corrections comparing with the experimental results mathematical models were used.

Like a conclusion of the experimental results we can do the affirmation that is not indicated the use of glass with composition type Pyrex, because during the incipient fusion process, "cristobalit" is formed, conducing to a rise in the thermal dilatation coefficient value. The "cristobalit" is formed amount others because of the presents of residual fluorine from decomposing of affinage agents. There for, the adversary effects of fluorine are eliminated in the presents of K_2O.

We appreciate that the objectives and the results provided in the realization plan were respected and accomplished in totality and the researches will successfully continue.

BACK

Research on fine bubble aeration technologies applied to wastewater treatment plants

Abstract: Theoretical and experimental researches regarding fine bubble columns dynamics and their interactions with liquids at rest or in motion are presented. The experimental results carried out in laboratory or pilot scale installations are in good agreement with the physical and mathematical models. The results finalized in implementing a modern aeration technology at RAGC Târgoviste.

Introduction

In the present stage theoretical and experimental aspects regarding the network bubble column (BC) operation and the validation of theoretical models respectively. The project was finalised by modernising an aeration technology using porous diffusers.

1. Theoretical research

The problem of interaction between bubble columns generated by porous diffusers and the flowing liquids represents a novelty from a scientific point of view, only particular cases being treated until now, as an example the interaction between bubble columns and liquids at rest [1], [3]. Numerical modeling of a network bubble column was made using Fluent code. The bubble movement at the free surface, the interactions between bubble columns, and the water movement induced by bubble columns can be detected. At the same time analyzing the pattern of bubble columns the minimum distance of assemblage for the porous diffusers was found to be l = 265 mm, l/d = 265/120 $\cong$ 2,5 respectively, where d represents the diffuser diameter. For a detailed study of mass transfer the classes diameter of bubble population must be analysed together with the evolution of these classes (fig.1.1 and fig.1.2).

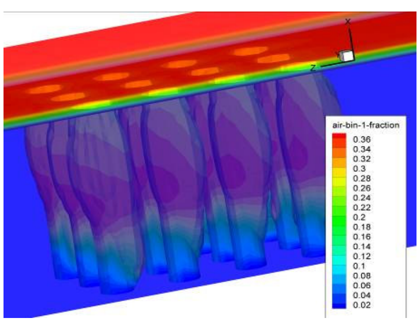


Fig.1.1, The density of the class of bubbles with diameter d = 0.0019 m

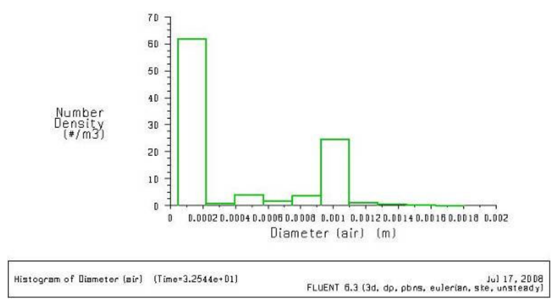


Fig. 1.2, The distribution of Sauter diameter for the classes of bubbles from tank

The theoretical basis is assured by the theory of the population balance model presented in the second stage of the project.

2. Experimental installation for studying the porous diffusers (PD) operating in network

The following installations have been successively accomplished in order to validate the theoretical models:

- installation for determining the hydro-gas-dynamic performances of PD (installation accomplished in the second stage of the project) which allows the determination of the pressure drop (in function of the gas flow rate) and the mass transfer. In this installation the glass PD Φ50 have been tested.

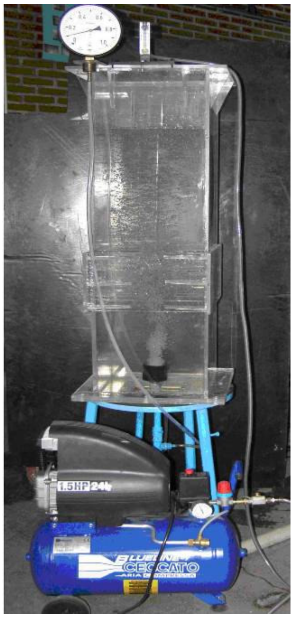


Fig. 2.1, Installation for testing one PD Φ50

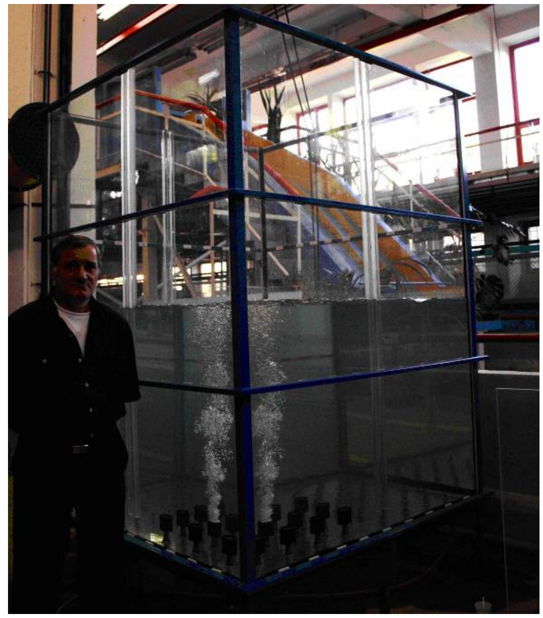


Fig. 2.2, Installation for testing a network of PD Φ50

- installation for determining the performances of a network of PD Φ50 (fig. 2.2),
- installation at scale of the aeration basin from RAGC Targoviste (fig. 2.3),
- installation for determining the mass transfer in situ (fig. 2.4).

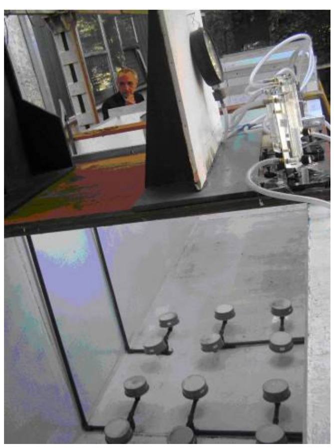


Fig. 2.3, Experimental setup

Fig. 2.4, Installation for determining the mass transfer in situ

The experimental setup from figure 2.2 having the dimensions 1.5m x 1.5m x 2.0m have been realized for lab studies concerning the operation of a network of PD. By isolating one or more PD the distances from this assembly assures variable distances among the bubble columns; these distances are necessary to elaborate the project of the in situ installation.

3. The project and the accomplishment of the in situ experimental setup

The installations shown in figures 2.1 and 2.2 solve the problems associated to the operation of the PD in still water [5]. For studying the interaction between the bubbles columns with the flowing liquid a new scale installation have been accomplished; this experimental setup consists in a network of PD Ø 120 disposed in an open channel already existing at the UPB-CCEPM partner. Four lines with PD, disposed in the cross direction towards the flowing liquid are disposed in the channel; on every line 3 PD Ø 120 are assembled (fig. 3.1 and 3.2). The average velocity of the liquid is 10 mm/s; the same value has been taken into account in the numerical simulation. The experimental setup is endowed with measuring apparatus (fig. 3.3); the flow rate and the pressure are automatically regulated from a control board.

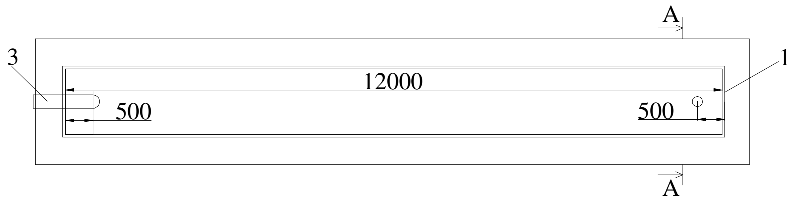


Fig. 3.1, Open channel (1- tank, 3 - fose Φ2”)

For accomplishing the similarity of this experimental setup with the aeration basin from RAGC Targoviste the Froude criterion was used:

$$Fr = \frac{V^2}{gH} = idem\,, \qquad (1)$$

where V is the velocity of the water, H – the depth of the basin and g – the gravity.

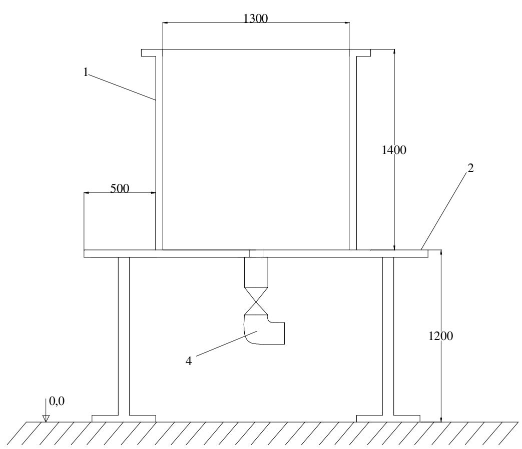


Fig. 3.2, Open channel – front view (1- tank, 2 – deck, 3 - fose Φ2”, 4 pipe with tap Φ2”)

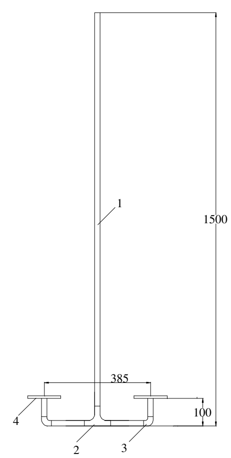


Fig. 3.3, Battery of PD, Φ120
(1- pipe Φ 1/2” X 1500, 2- three way pipe, 3 – bent pipe 90° 1/2”, 4 – PD Φ120)

4. Experimental results

The main issue studied with the help of the experimental setup shown in figure 2.3 is the flow induced by the bubble columns into the flowing liquid; this problem is essential for determining the mass transfer. For measuring the velocities induced in water a Micro ADV (**A**coustic **D**oppler **V**elocimeter) placed at different distances in the PD network had been used; the data have been recorded on line and the results have been compared with the ones obtained from the numerical simulation.

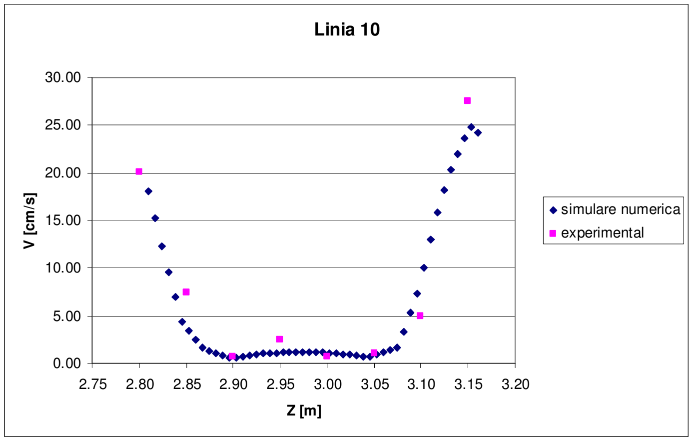


Fig. 4.1, The variation of the velocity *V* in function of the coordinate Z, at a distance X=20 cm from PD

One can see from figure 4.1 that there is a good agreement between the experimental and numerical values of the induced velocity. At small vertical distances from PD the induced velocity of the water has the allure of a parabola with a minimum (velocity almost zero) between two PD.

5. The validation of the mathematical models

The math model used for the numerical simulation in Fluent of the operation of the network of bubble columns is an Eulerian one, respectively the population balance model. This model uses a balance equation (similar to the mass, energy and momentum balance equation) for determining the modifications that appear in the bubble distribution. For obtaining different classes of bubbles the aggregation and break-down models are activated.

The bubble distribution is determined by using one of the following methods: discreet method, standard momentum method or quadrate momentum method [2], [4]. The transport equations from the population balance model and the momentum equations are coupled due to the drag defined by user taking into account the mean Sauter diameter calculated from the bubble distribution.

The numerical simulations have been accomplished in a rectangular domain having the dimensions 9000 x 1300 x 1400 mm and filled with water up to 1.2 m. The operation of the network of PD in flowing liquid has been simulated in the conditions in which the experiments have been carried out: the flow rate per PD 250l/h, the water velocity into the channel 10 mm/s.

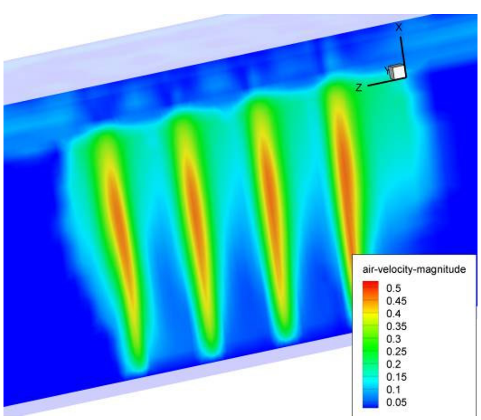


Fig. 5.1, Air velocity field for porous diffusers at y = 0,295 m

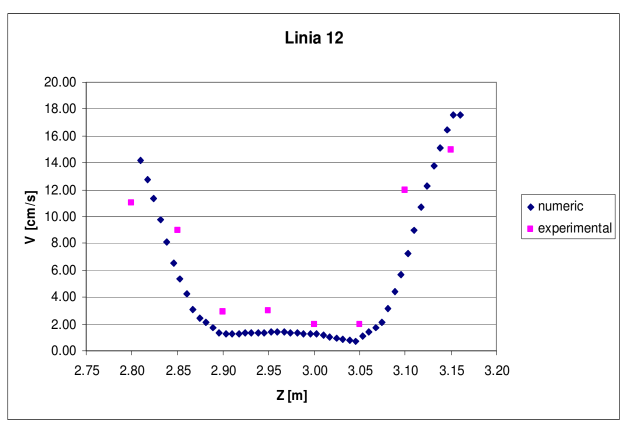


Fig. 5.2, Induced velocity variation at a distance of 40 cm from the diffuser, at the middle of the distance between 2 lines with porous diffusers.

Good agreement was found comparing the experimental and numerical simulation results. It was observed experimentally that the arrangement of the porous diffusers Ø120 at a distance of 265 mm one from another didn't lead to BC interference. This result was found also by numerical simulation as presented in figure 5.1.

6. In situ experiments (RAGC Târgoviste)

In the beneficiary's aeration basin, RAGC Târgoviste, a number of 36 elastic membrane porous diffusers Ø330 made by Automatizări Industriale IMAT SRL were assembled eccentric from the channel axes. The beneficiary co financed a part of the project and extended the number of the porous diffusers to 4 packs in order to cover the entire surface of the basin. The eccentric assemblage was adopted due to the idea that the induced movement of the water combine with the translation movement of the liquid, resulting in a helicoidally movement thus a longer contacting time.

Fig. 6.1, The operating of porous diffusers at a minimum level of water in the basin.

Fig. 6.2, The operating of the aeration installation in the basin at RAGC Târgoviste

The main problems to have in mind during the experiments at RAGC Târgoviste were: the operating security of porous diffusers and their response to possible accidental interruptions while operating the wastewater treatment plant. During a period of 45 days off operation, from 7 July 2008, accidental interruptions of the compressor station, took place each stop between 10÷70 minutes; it was ascertained that the porous diffusers work properly in the sense that no pore clogging was found (as in the case of the ceramic porous diffusers tested in the previous stages of the project), so these diffusers were found to be safe in operation

Regarding the mass transfer, the experiments carried out in the laboratory at RAGC showed that the dissolved oxygen varies between; 0÷4 mg/l that can be explained by:

- the canicular regime during the experiments;
- some minor deficiencies while operating the wastewater plant (variable quantities of active sludge).

Conclusions

During the project 4 experimental installations were developed, three of them in the last stage of the project. These installations allow determining the hydrogasdynamics performances of the porous diffusers in the lab (PD Ø 50) or at pilot stage (PD Ø 120) in static and dynamic regime, at maximum flow velocities of 20 mm/s.

The theoretical study regarding bubble columns dynamics in the network was made using FLUENT code, and the results are as following:

- bubbles injected at the bottom of the basin with the medium diameter of 300 µm, are subject to coalescence as rising to the free surface , reaching the diameters of approximately 5 mm;
- the mean residence time of bubbles in water is of approximately 3 seconds;

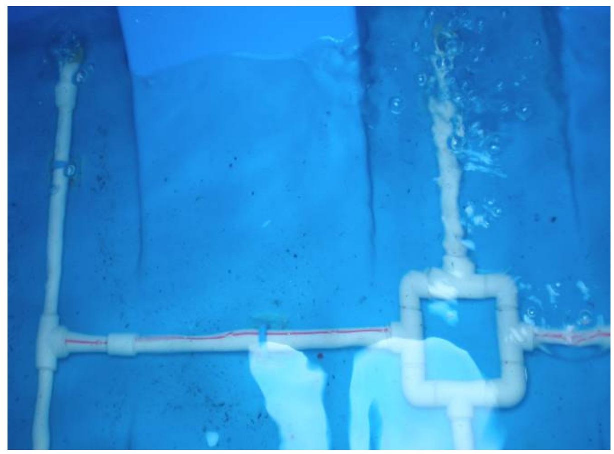
- The reciprocal influence of bubble columns in the pack can be noticed by the deviation of the columns at the periphery to the centre.
- The distance between bubble columns is correctly chosen, by avoiding BC interactions.

Measurements carried out in the dynamic regime validated the numerical solutions demonstrating the feasibility of the proposed solution.

The assemblage of the packs of porous diffusers at RAGC Târgovişte showed that these are operating properly even in the case of accidental stops.

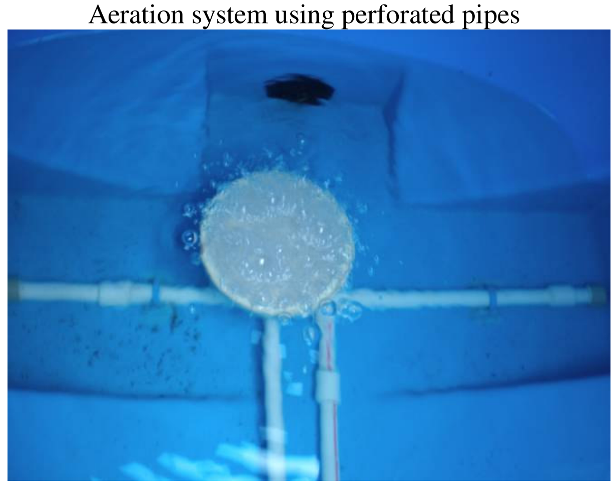
Possibilities of applying fine bubble aeration systems in other domains were also tested. In that sense the team from INCDIE ICPE-CA was asked to investigate the aeration possibilities in the containers for fish transport in order to replace the old aeration system using perforated pipes fed by an oxygen tube, which is an expansive and inefficient.

Containers for fish transportation



Aeration system using perforated pipes

The assemblage of the porous diffusers



Glass porous diffuser operating in container

Fig. 6.3

The assemblage of a glass porous diffuser in such a container led to efficient aeration, thus replacing the oxygen tube with a compressor charged from the car battery seemed to be adequate.

References

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BACK