INTEGRATING BIOTREATED WASTEWATER REUSE AND VALORIZATION WITH ENHANCED WATER USE EFFICIENCY TO SUPPORT THE GREEN ECONOMY IN EU AND INDIA

Work Programme 2012 "COOPERATION"

Theme 2: FOOD, AGRICULTURE AND FISHERIES, AND BIOTECHNOLOGY

Activity 2.3: Life sciences, biotechnology and biochemistry for sustainable non-food products and processes
Area 2.3.5: Environmental biotechnology
KBBE.2012.3.5-03
Biotechnological waste water treatments and reuse in agronomical system
Call: FP7-KBBE-2012-6

Integrating biotreated wastewater reuse and valorization with enhanced water use efficiency to support the Green Economy in EU and India

Grant agreement no.: 311933
Funding scheme: Collaborative Project
Coordinator: Dr Antonio Lopez, IRSA-CNR (Italy)

Water4Crops - EU

Work Package 3
Efficient water use in Irrigated Agriculture

Deliverable D3.2
Improved irrigation systems selection and maintenance methods to achieve higher water use efficiency and water savings

Due date: Month 36
Actual submission date: Month 42
Start of project: 1/08/2012
Deliverable Lead contractor: IRSTEA
Participants: IRSTEA, NERC
Authors: B.Molle, S.Tomas, N.Ait Mouheb
Contact for queries: bruno.molle@irstea.fr
Dissemination Level: PU

INDEX

1 Outlines of activities conducted in the framework of WP3 and main findings

1.1 On irrigation piping

1.1.1 Synthesis

The main activity focused on the understanding of the drivers of biofilm development when submitted to shear stress, i.e. when in contact with the flowing fluid. Experiments were conducted on PE pipes of various diameters (6, 16, 32 and 63mm) under various velocity (0.4, 0.8, 1.2m/s) of a 200mg/l COD fluid, used as a synthetic effluent, added or not with 125mg of 0 to 80µm size mineral particles. It was observed that in plain pipes biofilm grows in 2 phases: an initiation that generally lasts 20 days approximately, then a development phase that is similar in intensity in all velocity conditions. The velocity and shear (between 0.4-1.6 m/s and 0.74-12 N/m²) impact biofilm development cycles, the higher velocities first delay the initiation of biofilm development then the growing is equivalent to that observed under other velocities.

It is also suspected that biofilms developed under higher velocities are thinner but denser (Liu and Tay 2002). The frequency of water supply and the porosity of the biofilm are conditioning its nutrient supply and consequently its growth or compensation of abrasion. It has also been observed that, with a supply of water 8h a day, the portion of the pipes that were situated in the lower part of the network or where water is supposed to stagnate between two irrigations were showing the highest development.

Adding particles increases fouling, in mass, but decreases biofilm development probably because of abrasion phenomenon. In other words, the mass and density of deposits increases but the organic fraction decreases.

Concerning chemical precipitation induced by treated wastewater within pipes and emitters, we have been using PHREEQC software (geochemical model) to calculate solubility indexes and concentrations for each element as a function of temperature and pH. Experimentally, precipitation in beakers was used to validate the model results. pH measured at a tertiary treatment outlet (sand filter) from the WWTP of Mauguio (France) was 8.2 and total alkalinity was around 261 mg/l. By increasing the temperature from 26°C to 55°C and the pH from 8 to 9.5, the mass of formed precipitate raised 300 mg/l. Precipitates were analyzed by X-ray diffractometer 98% of the mass is composed of calcite ($CaCO_3$).

In all the experiment conducted, a large number of parameters influence the biofilm development which makes it difficult to isolate influencing parameters. Anyway the trends that was identified are all consistent with what is reported in the bibliography.

1.1.2 First conclusions on maintenance procedures in pipes:

Biofilm development is relying on nutriment supply, hydraulic characteristics (agitation, shear, velocity), time, fluid characteristics (temperature, pH, chemical elements) and raw material (PE, PVC). Considering that in a waste water reuse scheme it is not possible to control the nutritive content of the treated waste water, it will be advised:

- to regulate biofilm development from the definition of mechanical parameters in the design phase, keeping a sheer stress level higher than 10 N/m²,

- to respect emptying phases to weaken the biofilm periodically, and
- to operate chemical cleaning with a frequency that makes sense with the observed development of biofilm in a given situation.

From our experiment we could induce that hydraulic parameters alone could not prevent biofilm to develop, and that a cleaning frequency of two weeks could suffice to stay permanently in the initiation phase (that last 3 weeks). Adapting such practices to a given situation requires first observing biofilm development kinetics during a learning phase. It can be done adding a biofilm detector (several concepts have been developed, based on heath dissipation change over time of operation, or light propagation), another option is to keep in the network observation ports that will be mobilized only in a learning phase.

1.1.3 Questions still pending:

- Need to deepen the analysis of the effects of particles, understand the variation in biofilm density with velocity/shear stress, to be able in fine to propose a consistent model of biofilm growth;
- Need to characterize the biofilm detachment in terms of intensity and particle size produced to define flushing practices or drippers protection methods;
- Need to develop biofilm detection sensors adapted to irrigation networks (design and flow conditions) that allow early warning for maintenance needs;
- Need to study the effect of chemical precipitation, temperature and pH on biofilm development;
- Need to work on longer experiments to stabilize growth and to observe detachment that may be responsible in the field for a "secondary" drippers clogging phenomenon with biofilm detached from pipes.

1.2 On drippers

1.2.1 Synthesis

In Drippers with the same solution (1.1) added or not with 125mg of 0 to 80µm size mineral particles, biofilm clogging develops faster when velocity and shear are smaller; 2lph (liters per hour) drippers clog faster than 4lph (whether they are Pressure Compensating-PC or not-NPC) which confirms the effect of velocity/shear stress on biofilm development also in small section canals.

From Computational Fluid Dynamic (CFD) simulation we have identified hydrodynamic parameter of the flow inside the dripper. The flow is composed of a main stream and low velocity vortex downstream each of the baffles of the labyrinth. We have identified that the permanent flow regime is established from the third baffle. This flow is non-isotropic. Particle Image Velocymetry (PIV) experiments confirmed these results, but with intensities (i.e. velocity) 1.5 times smaller in the main flow.

The effect of hydrodynamic conditions and the identification of preferential zone on physical and biological clogging were also studied using optical analyses. Clay suspensions of sodium bentonite and kaolinite (200 mg/l), with or without 10-2M NaCl, and the synthetic effluent of 200mg/l COD were used. It was observed that particle deposit and biofilm formation occurs mainly close to the inlet of the labyrinth-channel, in the first baffles. Such development could be related to the higher turbulent kinetic energy values in these regions. The size of the particles also plays an important role in emitters clogging. The addition of salt in clay suspension led to the agglomeration of kaolinite particles, which favored their deposit in the labyrinth-channel. Biofilm development is observed as well after the first six hours of the experiment, until it reaches a maximum value in low velocity vortex zones, due to the time span of the experiment detachments were not observed.

1.2.2 First conclusions on dripper selection and cleaning:

- It is advised to preferably select higher discharge drippers, the larger flow path reduces the turbulent kinetic energy to dissipate at labyrinth entrance which delays the plugging by biofilm or particles accumulation, but will not prevent from applying cleaning processes;

- Such cleaning processes should apply on a regular basis after an observation or learning phase during which the variation in the emitters flow rate will be surveyed over a minimum time period of 2 months. Then cleaning frequency could be decided accordingly. It varies from weekly to monthly depending on the characteristics of water;

- From these experiments we also observed that biofilm development may be irreversible at reasonable cost if not cleaned regularly. It was observed that the bacteria may be killed by the treatment but the biofilm matrix (polysaccharides) is resistant to disinfection and may act as a mesh that traps particles transported by the water. A preventive maintenance is the key for the conservation of the distribution performance of a WWR drip irrigation system. In a previous work, using 9 different models of drippers, a time interval of 3 weeks between maintenance was found sufficient to prevent clogging of various drip irrigation emitters, including some models of drip tapes, when distributing a secondary effluent disposed from an activated sludge treatment.

It is advised:

- selecting drippers with a protection grid at flow path inlet that prevent biofilm detached to enter the flow path and permit initiation of biofilm development inside the flow path from deposit during the stop phases;

- choosing non PC instead of PC drippers that revealed more sensitive to biofilm development;

- decreasing as much as possible low velocity zones while keeping turbulence and head losses capacity of the labyrinth;

- meshing irrigation piping inside irrigation blocks to reduce low velocity area and ease flushing operation.

Regarding the selection of drippers some are recognized to be highly sensitive to clogging when others are less. An industry oriented test is operated in Irtsea’s laboratory that can help giving such indication on the different models of drippers. A list of drippers already tested is available on-demand. Further the protocol operated on such issue is under discussion at ISO and may result in a standard shortly.

1.2.3 Questions still pending:

- To work on longer experiments to stabilize growth and to observe detachment that may be responsible in the field of a “secondary” clogging phenomenon with biofilm detached from pipes;

- To approach the effect of dripper's filter at labyrinth-channel entrance to prevent biofilm particles entrance and/or deposit;

- To enlarge the spectrum of velocity/shear stress combinations;

- To calibrate a model that relates biofilm growth rate with hydrodynamic parameters to operate in CFD simulations;

- To deepen the approach combining biofilm and particle effects on drippers performance working with micro-canals similar to drippers labyrinth;

The use of PIV as an investigation tool showed its high interest, in order to increase flow resolution obtained, it is anticipated to use smaller particles (1 µm) as tracers. Such small particles, that don't interact with fluid movement, will allow describing the flow all over the profile and in particular near the dripper's wall. Further adapted particle tracking velocimetry (PTV) method has to be developed to analyze real particle path, aggregation and deposit processes. Coupling PTV with PIV will allow studying particle/flow interactions and to develop/adapt two phase flow simulations;

1.3 Design and testing of an emitter dedicated to treated waste water distribution

1.3.1 Synthesis

An emitter (DA-EU) specific to distribute low quality waters has been developed, patented and tested during the project. It includes a membrane and is designed to maintain the highest possible velocity of liquid in the emitter to avoid any particles deposit or biofilm development that may result in progressive clogging. The deformation of the Silicon membrane, used as flow regulation device, has been successfully simulated. Its real time interaction with the flow is still to be modeled to make further progress on design.

A number of prototypes have been produced from 3D printing that reveal too fragile, after a two months test, to withstand the operating pressure (up to 400 kPa) of a standard irrigation system. We have then been using it with a lower pressure and its capacity to operate intensively on raw waste water during more than 500h without any maintenance has been confirmed. It has to be noted that the effluent disposed from the reed bed system was not filtered during this experiment. The same device has been evaluated with water added with bamboo fibers to evaluate its capacity to withstand any similar contaminants such as filamentous algae. The use of such fiber is justified because they can be provided in standardized size series.

1.3.2 Question still pending and perspectives:

- The delivered flow rate ranges from 100 to 150 l/h initially, we reduced it to 60-80l/h, we intend to decrease it under 50l/h to better fit localized irrigation characteristics. The development of the numerical model coupling fluid and mechanical behavior will help in this purpose;

- The production of stronger prototypes (base on molding) is to be done to evaluate it under more tough conditions and identify the max size of particles that are able to path through. The objective is to define the size of filtration required.

1.4 Evaluating transport potential of small droplets emitted by sprinkler under field conditions:

1.4.1 Synthesis

The amount and travel distance of droplets submitted to transport were measured downwind from a sprinkler currently used in turf irrigation with a radius of 13m. The experimental method, defined within the project, used PVC strings tightened downwind from the sprinkler and perpendicular to its direction, and petri dishes positioned on soil surface. Such collection systems allowed collecting volumes of less than 0.5ml/m²/h at distances up to 50m from the sprinkler. Such volumes were either transported by the air and/or possibly deposited on the soil surface. A non-linear empirical model that adjusts the measured deposit is proposed. It gives a good estimation of deposits and transported particles when considering: distance, wind velocity, wind direction, ET0 and non-dimensional numbers (Weber and Froud) that characterize the atomization process.

Further CFD and Gaussian simulations have been performed in order to propose a model for droplet drift and transport giving a good correlation with experimental results. For both approaches, initial conditions of the dispersed phase (droplets) have to be fixed as inputs (a typical droplet diameter range and their flow rate). Results are strongly depending of these parameters.

In terms of management of sprinkler irrigation when reusing treated waste water, it clearly appeared from the experiments that drift potential remains low compared to the quantity of pathogens that could be detrimental to human beings when inhaled or exposed by contact. Nevertheless a step in the volumes transported appeared in the measurement close to 4m/s wind velocity. Thus if any restriction could apply to such reuse practice, and considering that pathogens are able to survive to such dispersion, a wind threshold of 4m/s (15km/h) measured at 2m above the ground, during a 10 minutes time span, will protect against most of the transport of sprinkled particles. Such prescription has been integrated in the French regulation and can be considered as an output of the project. This result has been presented in the framework of the expertise conducted by DG-ENV in the view of establishing a European directive of the subject of reuse.

1.4.2 Questions still questions

- The possibility that dry aerosols could escape the measurement area and not be collected by the capture method operated;
- The survival of pathogens in flying droplets is poorly studied, a better knowledge will help defining reasonable sprinkler practices thresholds;
- The investigation of a larger spectrum of sprinkler emitters and pressure conditions to be more representative of existing technology and practices;
- Numerical modeling of aerosols dispersion needs more investigation.

2 Defining the characteristics of the irrigation network

2.1. Synthesis

As observed in the dedicated experiments, the velocity of the flow itself does not prevent biofilm development. It occurred in our experiments whatever the velocity between 0.4 and 1.6m/s. With lower velocities the development initiates more rapidly than with higher, where the initiation phase lasts around three weeks in the experimental conditions we have implemented. The duration of this initiation phase is to be determined in each situation, in a sort of learning process, to plan the cleanings consistently.

On one hand, from what was observed, part of the clogging that ends up in the drippers is originated from the detachment of small biofilm elements that enter the dripper's flow path. Flushing such detachment out of the irrigation pipes is a solution to better prevent the drippers from getting clogged by biofilm detached from the pipe walls. This could be achieved under velocities of water that pass 2 m/s (preferably 3 m/s) and during short cleaning phases. Such flushing could easily be achieved if the field network is correctly meshed and equipped with valves that allow isolating portions of the network with a flushing valve at the outer end of each block. Such design makes it possible to allocate more energy on restricted parts of the network successively, resulting in higher pressure, velocity and flushing effect on each portion.

On the other hand if we want to prevent chemical precipitation, it is required to minimize the changes of phase and minimize the possibility to have water that heats and evaporates in the piping system. Consequently if such source of clogging is predominant, and the system not exposed to high temperature (i.e. not exposed to the sun light), it is advised to keep the network full as much as possible. In the case of surface piping system the temperature inside the pipes have been measured over 55°C in Mediterranean conditions which may help significantly scaling. The only solution to reverse such source of clogging is to operate periodically a cleaning with acid solution (chlorhydric or sulfuric) that will dissolve the precipitate.

Regarding the pipes material, some tests were conducted on PE and PVC and clearly showed that biofilm develops in both cases. But this development is much more intense (about 5 times) on PE pipes than PVC.

2.2. The questions pending concern:

- What is the effect of dry/wet phases in the piping network on biofilm growth and detachment;
- The use of simple flushing combined with network emptying is probably a good non chemical solution to help cleaning the network, its combination with chlorination for example is to be tested in lab then in a real situation to adjust timing and doses;
- Investigate on mid-term (2-3months) the effect of temperature on scaling in field conditions;
- Better investigate the dosage of disinfectant or acid to inject, the frequency, the time of exposure… in cleaning processes.

3 Emitters selection criterion

A few investigations were conducted in this purpose but not enough to draw solid conclusions. What was observed could be summarized as follows.

3.1 Drip irrigation emitters:

- NPC drippers seem to better resist to biological clogging compared to PC. The membrane in PC emitters could be bothered by the presence of biofilm that generally develops in the area of lower velocity. This results in a progressive increase of the heterogeneity of distribution with time that may soon generate large fluctuation over an irrigated plot;

- In terms of nominal discharge the 4lph is resisting better than the 2lph, and the 1lph. Nevertheless, from previous studies it has been demonstrated that even 1lph drip tapes, considered very sensitive to clogging could be maintained over two seasons provided maintenance operations are closely followed;

- The conjunction of solid suspended particles and nutrients in the water tends to increase the development of deposits dry mass, but doesn't affect rapidly the discharge. On the opposite the adding of nutrients without particles results in clogging phenomenon that affect the discharge but with a much lower dry mass, over eight weeks of a recent experiment (out of the project scope).

3.2 Specific localized irrigation emitter

Regarding the specific emitters dedicated to treated waste water, it was tested in real conditions with water containing:

- The DA-EU confirmed capacity to operate with raw water was validated on a period of more than 500h, but only some of the prototype samples resisted to long term operation. Nevertheless the concept confirmed its potential that has to be comforted now;

- Calibrated nozzles (25 to 60lph between 30 and 100kPa): this solution is under long term evaluation (2 years) in a work conducted in parallel to W4C project with a sceptic tank effluent that is filtered in a reed bed to supply irrigation for fast growing trees for energy production. Short terms test with mineral particles and nutritive waters confirmed the capacity of these emitters to distribute low quality waters effectively.

- Micro-sprinklers: on the parallel experiment cited above some micro-sprinklers were evaluated (35lph) under 100kPa with a 135µm filtration. After two years of operation, they showed a good potential to resist to clogging without any more cleaning procedure than monthly flushing of lateral lines.

3.3 Sprinklers irrigation

The work focused on a sprinkler that is currently used in turf irrigation and that is dispersing its jet sooner (closer to the nozzle) than agricultural type sprinklers. The volumes drifted and the travel distances of droplet population are the key points. Such parameters have to be injected in a risk analysis equation (such as QMRA) to draw conclusions. The problem remains that such an evaluation could not be conducted for respiratory pathogens which are assuming the highest risks. Up to now (except legionella Pneumophila) such pathogens have not been investigated in terms of survival and infectious capacity when dispersed in the air… probably because no problem occurred until now?

Anyway, a compromise between nozzle size, range and pressure, that determines the size of particles and their behavior under windy conditions will have to be found for each operating conditions in a prevention perspective. This will mainly rely on the potential population exposure (frequency and duration of exposure, distance from irrigated area)

4 Conclusions

The different conclusions listed in the present document were extracted from the results of various experiments and calculation conducted in the framework of the present project or former projects. The detail of the investigations conducted is given in the scientific report and Deliverable 3.7 developed by WP3 under Task 3.3 Improving irrigation performance to increase water use efficiency, prevent adverse impacts and assure durability, and sub-tasks associated:

- Sub-task 3.3.1 Biofilm development under shear stress conditions: Emitter performance with mineral particles;
- Sub-task 3.3.2 Simulation of the fluid mechanics within a dripper flow path;
- Sub-task 3.3.3: Testing the pressure regulated emitter adapted to quasi raw waste water;
- Sub-task 3.3.4. Evaluating the drift potential of small water particles emitted by a sprinkler under field conditions.