Study of atmospheric dispersion mechanism of contaminants: Case of treated wastewater reuse land applied sprinkler

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I. Context

Treated wastewater reuse (TWWR) helps to meet growing water demands, reduces degradation of the quality of conventional water resources and contributes to soil fertilization. But, TWWR requires irrigation methods that minimize risks for health and the environment.

At the international level, guidelines and recommendations have been developed based on health risk assessment processes, which form the background for most of the proposed guidelines on TWWR in other countries (Aquarec project, 2006; EPHC/NRMMC/AHMC, 2006; EPA, 2012). France has recently adopted regulations concerning the treated wastewater reuse for sprinkler irrigation, including the use of water from urban wastewater treatment plants for field crops or green spaces irrigation (ANSES, 2012; NOR-AFSP1410752A, 2014; NOR-TREL1803081A, 2018). However, there is still lack of knowledge about dispersion of inhaling pathogens such enteric viruses or toxic contaminants by sprinkler irrigation.

Generally, dispersion mechanism and survival of pathogens depends on several factors such as atmospheric conditions (wind speed, relative humidity, ambient temperature and solar radiation), spray characteristics (Nozzle type, droplet size, initial velocity), operating conditions (spray unit, target properties, operator's skills), morphological and biochemical characteristics of the pathogens and their seasonal variation (Donnison et al., 2004; Karadag et al., 2012; Chang et al., 2013).

Molle et al (2009) found that most of the droplets subjected to drift have a diameter inferior to 150 microns, representing less than 3% of the total volume of water applied by the most common models of sprinklers, the volume that has been neglected by the majority of researches.

Among atmospheric conditions, wind plays a major role by dispersing aerosols outside the effective radius of throw. Very small particles (less than 5 µm in size) and pathogens can travel several kilometers before easily entering the respiratory tract of humans by inhalation (Fannin et al. 1976; Yang et al. 2018).

Therefore, sampling such small volume of water and characterizing particle size, which can be transported, and its quantity represent a challenge. So far, a wide variety of bioaerosol sampling methods (passive and active methods related to pumps) is used and many other methods are still under development (Willeke et al., 1993; Cox and Wathes, 1995; Sutton, 2004; Cartwright et al. 2009; Wu et al., 2013). However, there are always limits when sampling aerosols below 100nm. In addition, each type of sampler has its own advantages and disadvantages and it is therefore more effective in different circumstances. Also, fewer studies were investigated field sampling and pathogen dispersion with TWW (Brooks et al., 2004; Dungan, 2010; Wery, 2014).

So, the **main objectives** of this thesis are to:

- Evaluate recent techniques and methods used for aerosol detection and sampling→ Develop robust collection protocols to quantify fine particles (-> nm= virus).
- Analyze and simulate (physical and numerical) dispersion mechanisms for different atmospheric and technical conditions from the laboratory to the real case→ participate in the implementation of guidelines for TWWR in sprinkler irrigation.

II. Materials and methods

- Aerosol test system

The LGEI laboratory of IMT-Mines Alès, in partnership with the companies Europe Environnement and Bruk'Air, has developed a sampling chamber associated with an aerosol generator presenting a laminar flow with a velocity v = 0.09 $m.s^{-1}$ (400 $l.min^{-1}$, Re = 2300). The aerosol generator consists of the nebulizer flowmeter (Q_NEB) and the dry flowmeter (Q_DRY) which can respectively go up to 100$l.min^{-1}$ and 600$l.min^{-1}$. Liquid suspension of each test tracer was dispersed by an ultrasonic humidifier (U7146, Boneco) that has been installed in a 40l tank. The Q_NEB is injected into the tank through a pipe that carries the aerosols produced at the outlet of the generator and prevents them from falling to the bottom of the tank. The purpose of Q_DRY is to dilute the generated aerosols being evacuated by a flow of air Q_(GE)[***figure 1***].

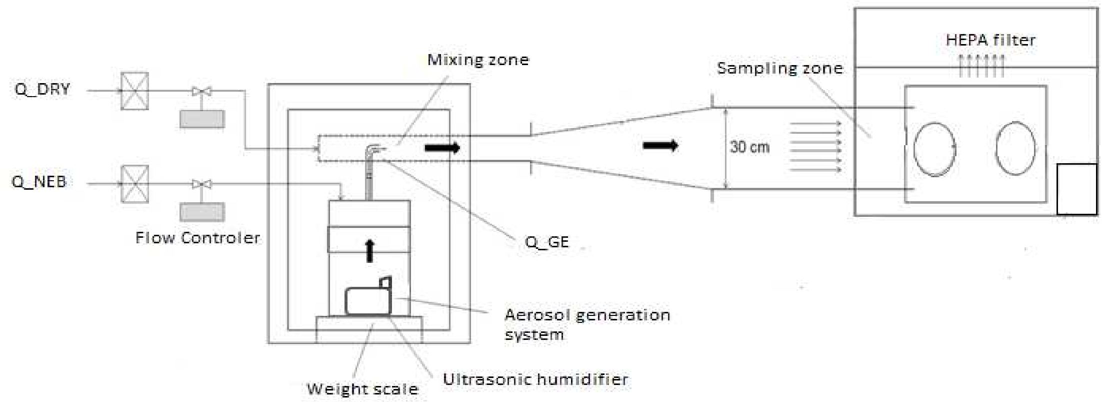

Fig1: Schematic diagram of aerosol test system

This aerosol test system aims to meet the following objectives:

1. Evaluation of the physical, biological and recovery efficiency of active samplers: impingers(AGI-4 and SKC BioSampler with sampling flow rate of 6$l.min^{-1}$ and 12.5$l.min^{-1}$, respectively), Real-Time viable particle counter (BioTrak) and filtration (glass fiber filters (as a reference) and gelatin filters, held by a 37-mm 3-piece cassette), at the different sampling times (5min, 15min and 30min) and by two tracers: a fluorescent tracer (ABF) and *Escherichia coli* bacteria [ATCC 15597];
2. Evaluation of the possibility of simulating Escherichia coli bacteria by 1µm Polybead® microspheres for subsequent experiments in wind tunnels.

- **Wind tunnel**

The IMT-Mines Alès open-circuit wind tunnel with a working section 2m long, 0.5m wide and 0.35m high is capable of generating wind speeds up to15 $m.s^{-1}$. The transparent plexiglass walls (Thickness: 10mm) facilitate optical measurements, such as particle image velocimetry (PIV), laser particle Doppler analyzer (PDA) as well as visualizations. Two aerosol generators, ultrasonic humidifier (U7146, Boneco) and extremely fine, axial-flow hollow cone nozzle (220.0851Y, LECHLER) are used respectively for simulating inhalable aerosols (<10micron) and droplet (< 200 micron). The tasks envisaged in the wind tunnel are to develop robust sampling methods and analyzer dispersion processes under controlled conditions.

- **Field study**

Evaluation of drift and transport under field conditions and for different sprinkler techniques and atmospheric conditions will carry out on a plot cleared of all obstacles (200 m upwind and 100 m downwind), and located at the Domaine du Merle site (SupAgro Montpellier). Molle et al (2016) analyzed drift and transport of a Rain Bird (RB) 5000+ sprinkler, which is commonly used in parks and gardens. Our research will investigate atmospheric dispersion of different sprinklers.

- **Computational Fluid Dynamic(CFD) model**

In the ANRT-Nowmma, FP7-W4C, FUI-SFR and BEI N7 projects, the Drift-Flux model (CFD) was used under ANSYS and developed under Open foam by SmartFertReuse's equip (I. Cornacchia). It follows the Eulerian approach and takes into account the physics of droplets (particles) through a sedimentation rate that has been modified to take into account their evaporation. The main advantage over the Lagrangian approach is the reduction of calculation time. The aim of this study is to deepen the sensitivity analysis as well to validate / compare with experimental data.

III. Results

The experimentation results in the aerosol test system show that when impingers operated in their most common mode, with 20ml of deionized water at nominal flow rate and sampling time of 15 min, for every 1-degree increase in ambient temperature, 0.1ml of water evaporates. In addition, the liquid evaporation/aerosolization rate for impingers, SKC Biosampler and AGI-4 at the temperature of 25°C was respectively, about 0.19 $ml.min^{-1}$ and 0.14$ml.min^{-1}$ (**figure 2**). Whereas previous studies (Lin et al., 1997; Willeke et al., 1998) observed a rate of 0.2 $ml.min^{-1}$ for AGI-4 at the flow rate of 12.5$l.min^{-1}$ and at a temperature of 25°C, it can be concluded that aspiration debit affects the collection efficiency of the impingers.

Figure 3 shows that physical collection efficiency of AGI-4 is higher than SKC Biosampler for sampling fluorescent tracer of the inhalable liquid aerosol (between 0.5µm and 3µm) at different sampling times (5, 15 and 30min). Inversely, biological efficiency of SKC BioSamler was much better than AGI-4 and became the best as the sampling time of 15min for collecting *Escherichia coli* bacteria. Moreover, the glass fiber filter and gelatin filter demonstrated the worst biological efficiency (too low to quantify) of all tested samplers. Indeed, using filter can lead to higher physical collection efficiency, but can damage the viability of bioaerosol (Roux et al. 2016; Yang et al. 2011). By comparing the amount of collected *Escherichia coli bacteria* with impingers (culture technique) and those counted by BioTrak, it seems that BioTrak provides rapid but less accurate number of viable particles. It should be noted that these results were obtained at very modest relative humidity (in the range of 10-15%) and the experiments are still in progress.

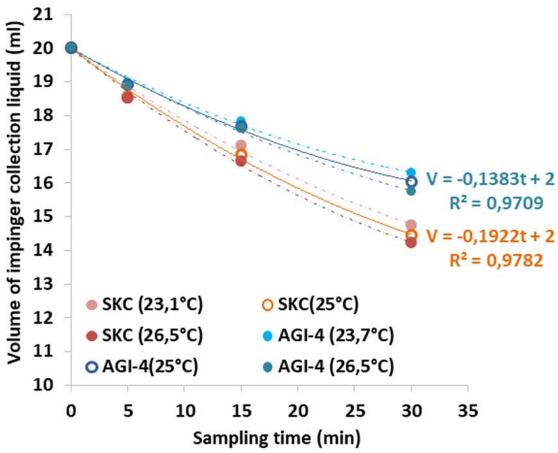

Fig. 2. Liquid evaporation/ aerosolization rate of impingers at different sampling times

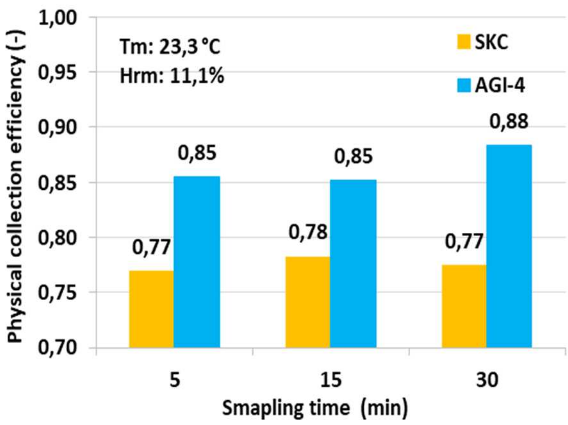

Fig. 3. Physical efficiency of impingers at different sampling times.

Conclusion

Given the experimental constraints, the implementation of sprinkling processes under actual conditions of TWWR is not envisaged at this research. To assess the biological efficiency of actives samplers, Escherichia coli (E. coli) has been used in aerosol test system as a virus indicator organism due to its high resistance to environmental degradation. In addition, fine droplet dispersal generated by sprinkler as a major vector of contaminants transport, is investigated by a fluorescent tracer (ABF) which has a low light degradation rate and is the most sensitive to drift and transport analysis techniques compared with other fluorescent tracers.

According to the results obtained in aerosol test system with ABF, AGI-4 impingers can be utilized in the field studies by arranging a vertical grid at different distances downwind of sprinklers. This allows to measure airborne spray profile. On the other hand, SKC Biosampler was developed to improve the sampling times (up to 8 hours) using non-evaporating liquids such as ViaTrap® mineral oil. So, it can be also used for measuring the fine particle transport after irrigation by sprinklers, which was not previously possible to evaluate with passive collectors and due to the generation of several errors using AGI-4 impinger because of regular replenishment of the collection liquid.

IV. Questions

- I am doing an experimental research on transport of fine particles by sprinkler irrigation does anyone have some experience feedback about this subject apart from the bibliographic ref listed below?
- Would it be better to discuss field measurements? In connection with what I wrote above?

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