Available online at www.sciencedirect.com

ScienceDirect

journal homepage: www.elsevier.com/locate/issn/15375110

Research Paper

Reducing energy requirements for sand filtration in microirrigation: Improving the underdrain and packing

Josep Bové [a], *Gerard Arbat* [a,*], *Toni Pujol* [b], *Miquel Duran-Ros* [a], *Francisco Ramírez de Cartagena* [a], *Joaquim Velayos* [b], *Jaume Puig-Bargués* [a]

[a] *Department of Chemical and Agricultural Engineering and Technology, University of Girona, Carrer Maria Aurèlia Capmany 61, 17071 Girona, Catalonia, Spain*

[b] *Department of Mechanical Engineering and Industrial Construction, University of Girona, C. de Maria Aurèlia Capmany, 61, 17071 Girona, Catalonia, Spain*

ARTICLE INFO

Article history:
Received 16 July 2015
Received in revised form
9 September 2015
Accepted 17 September 2015
Published online 22 October 2015

Keywords:
Drip irrigation
Nozzle
CFD modelling
Pressure drop
Energy consumption

Energy consumption in pressurised irrigation systems has become a major issue, even when microirrigation is used. Although the emitters used in microirrigation operate at low pressures, their filters require higher pressures and there is therefore no reduction in energy consumption. Part of the pressure drop found in filters is produced by the porous medium itself and this cannot be avoided. However, a large part of the pressure dissipated is caused by auxiliary elements of the filter and this could potentially be reduced without reducing the effectiveness of the filtration process. The auxiliary elements that produced most of the pressure drop in a sand filter were identified. The pressure drop in a scaled sand filter was measured at different points. A computational fluid dynamics (CFD) model of the filter was developed and validated using experimental data. Good agreement was observed between the measured and predicted pressures at the different locations. The CFD model was then used to analyse the regions and elements that produced most pressure drop in the filter and a new underdrain designed to reduce pressure drop was developed. It was predicted that the total pressure drop produced by the underdrain could be halved. In view of these results, a new underdrain design and packing strategy was proposed which could reduce the overall pressure drop in the filter by 35%.

* *Corresponding author*. Tel.: +34 972 41 84 59; fax: +34 972 41 83 99.
E-mail address: gerard.arbat@udg.edu (G. Arbat).

http://dx.doi.org/10.1016/j.biosystemseng.2015.09.008

Nomenclature

a	Fitting parameter of a second-order polynomial equation with a zero intercept
b	Fitting parameter of a second-order polynomial equation with a zero intercept
CFD	Computational Fluid Dynamics
C_2	Inertial factor, m^{-1}
GCI	Grid Convergence Index
N	Number of observations
N_1, N_2 and N_3	Number of elements used in each case to discretize the quarter section of the filter
NSE	Nash and Sutcliffe coefficient of efficiency, dimensionless
n_t	Number of times that the variability of the observations was greater than that of the RMSE, dimensionless
O	Average observed pressure loss, kPa
O_i	Observed value of pressure loss, kPa
P_i	Predicted value of pressure loss, kPa
R^2	Coefficient of determination
RMSE	Root mean square error, kPa
SD	Standard deviation, kPa
v	Superficial velocity, m s^{-1}
Δp	Pressure drop across the filtering medium, kPa
ΔL	Length across the filtering medium, m
α	Viscous factor, m^2
ε	Media porosity, dimensionless
μ	Water viscosity, Pa s
ρ	Water density, kg m^{-3}

1. Introduction

Microirrigation is an irrigation method that purports to achieve high water use efficiency whilst requiring low pressure, which is why numerous references claim that energy consumption is low when using this system (Ayars, Bucks, Lamm, & Nakayama, 2007). However, numerous examples worldwide have shown that energy use increases when microirrigation is adopted (Burt, Howes, & Freeman, 2011; Corominas, 2010). In Spain energy demand for irrigation has been rising in recent decades, despite an improvement in irrigation efficiency, and evidence shows that energy consumption has increased by a factor of 19 from 1995 to 2007 (Corominas, 2010; Pardo, Manzano, Cabrera, & García-Serra, 2013). Current high energy prices have resulted in a reduction of profits for farmers (Pardo et al., 2013) and reducing energy consumption has now become a higher priority than decreasing water consumption (Hardy & Garrido, 2012).

Burt et al. (2011) questioned why, if emitters only need a pressure of 41–82 kPa, the average pump discharge pressure on flat ground in California, USA is 310 kPa. They indicated that by improving the design of sand filters, the pressure required by the microirrigation system could be significantly reduced. Arbat et al. (2011), using Computational Fluid Dynamics (CFD) to predict pressure drop in the different elements of a commercial microirrigation sand filter, showed that more than 15% of the pressure drop was produced in the auxiliary elements. Mesquita, Testezlaf, and Ramirez (2012), in an experimental study that analysed the effect of the internal auxiliary elements in different commercial sand filters, concluded that different existing configurations of internal auxiliary elements, such as the underdrain and the diffuser plate, greatly affected the pressure drop. These previous studies clearly indicated the need to improve the auxiliary elements from the point of view of energy efficiency. Arbat et al. (2013), in an experimental study with a scaled commercial sand filter testing different sand media depths, showed that most of the pressure drop occurs at the bottom of the sand column and in the nozzle. These authors developed an analytical model to predict pressure drop in sand filters taking into account the effect of the underdrain. This analytical model improved the pressure drop predicted by the Ergun equation and showed the importance of the underdrain geometry since its interaction with the filtration media greatly affected the total pressure drop across the whole filter. Using a flow tunnel, Dos Santos, Mesquita, and Testezlaf (2013) experimentally confirmed the importance of underdrain design in the flow-line trajectories. De Deus, Testezlaf, and Mesquita (2013) studied the effect of diffuser plate dimensions on pressure drop and on deformation of the sand bed surface. They concluded that the different diffuser plates did not change the pressure drop but an improved diffuser plate could reduce the deformation of the sand bed and therefore reduce the effects of preferential water passages.

From the above research, two different components of the total pressure drop in a sand filter can be distinguished: that produced by the filter media and that produced by the filter components themselves. The former is necessary for the filtration process, but the latter could be minimised to reduce energy requirements and thus optimise energy efficiency in sand filters.

Although analytical models can predict the pressure drop caused by the different auxiliary elements of a sand filter (Arbat et al., 2013), these types of models cannot consider realistic geometries, and predicting the pressure drop with new designs is therefore not straightforward. On the other hand, CFD techniques could allow realistic geometries to be defined. Previously, CFD models have been used to analyse wall effects in packed beds (Miroliaei, Shahraki, & Atashi, 2011; Palle & Aliabadi, 2013; Reddy & Joshi, 2010) and to predict the pressure drop in a microirrigation sand filter (Arbat et al., 2011). In the latter case underdrain geometries were simplified in order to perform the simulations in a reasonable time and only one point of pressure-flowrate was simulated.

To attain greater knowledge of the effect of the auxiliary elements on the pressure drop, and quantify energy losses throughout the filter, a realistic geometry of a scaled commercial sand filter widely used in microirrigation was modelled using different pressures and flowrates and different filter media. The main goals were: (1) to identify the elements that produce most of the pressure drop; (2) to propose ideas for reducing unnecessary energy losses in the filter so as to achieve higher energy efficiency; and (3) to design a new underdrain which reduces pressure drop.