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Research Paper

Development of head loss equations for self-cleaning screen filters in drip irrigation systems using dimensional analysis

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Two equations for computing head loss in self-cleaning screen filter when using tap water and sand water mixture were developed using dimensional analysis. The parameters influencing head losses were considered to be eleven parameters representing the filter properties; filtration level, total filtration surface, flow rate, concentration of total sand, filtration time, inside diameter of the inlet and outlet pipes, mean filtration velocity, mean diameter of sand particle size distribution, water viscosity and water density. These variables were incorporated into eight dimensionless groups obtained through Buckingham's method. Two experiments to analyse head losses were carried out using 178 μm and 124 μm screen filters. A total of 54 runs for tap water and 58 filtration cycles for sand water mixture were carried out to obtain 54 and 2152 experimental points respectively, enabling the developed equations to be correlated. The developed equations were satisfactorily adjusted using the experimental data. Despite the adjustments of the equations being significant, regression coefficients were not always high. A comparison between the predicted and the measured head losses with three screen filters was in close agreement with a correlation coefficient of 0.902 for tap water and 0.832 for sand water mixture, respectively. The performance of equation was also compared with equations developed from the literature. The equations from Puig-Bargués et al. (2005b) Biosystems Engineering, 92 (3), p383–390 and this study provided good predictions, compared to other equations available in the literature.

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Nomenclature

A	total filtration surface, m^2
a, b, c	empirical coefficients
D_p	inside diameter of inlet and outlet pipe, m
d_{50}	median diameter of sand particle size distribution, m
f, g	functions
$k_1, k_2, k_3, k_4, k_5, k_6, k_7, k_8, k_9, k_{10}, k_{11}, e_1, e_2, e_3, e_4, e_5$	empirical exponents
L	length
M	mass
m	number of variables
Q	flow rate across the filter, $m^3\ h^{-1}$
R^2	regression coefficients
RMSE	root mean square errors
S	concentration of total sand, kg m^{-3}
T	time
t	filtration time, s
V	water volume across the filter, m^3
v_f	mean filtration velocity, m.s^{-1}
ΔH	total head loss across the filter, Pa
ρ	water density, kg m^{-3}
μ	water viscosity, Pa s
π	dimensionless group
Φ_f	filtration level or filter pore, m

1. Introduction

Among irrigation systems, drip irrigation is one of the most efficient methods because, amongst other advantages it can improve water efficiency, apply agricultural chemicals more efficiently, reduce fertiliser costs and reduce nitrate losses (Shock, 2006). However, a recurring problem with drip irrigation is the clogging of emitters, which is directly related to water quality and filtering system efficiency. Keller and Bliesner (1990) stated that the clogging of drip emitters is the largest maintenance problem with drip irrigation systems whilst Capra and Scicolone (2004) implied that the clogging of emitters was difficult to detect and it was expensive to clean, or replace clogged emitters.

The main reason for emitter clogging is suspended solids which can have both organic and inorganic components. However, the greatest clogging problems are caused by the presence of materials such as silt and algae (Adin & Alon, 1986). Problems encountered due to clogging can be prevented by proper filtration and chemical processing (Gilbert & Ford, 1986). Filtration is defined as the separation of solid materials by using their physical properties with proper filtration providing clean water. Filtration is essential to the efficient operation of drip irrigation systems and also it extends their operating life.

A variety of filters has been developed in order to facilitate drip irrigation. Some of these include sand separators, media filters and screen and disc type filters (Benami & Ofen, 1993; Demir & Uz, 1994; Douglas & Bruce, 1985; Keller & Bliesner, 1990). In China, in the area operated by the Xinjiang Production and Construction Corps (XJPCC), there are about 870,000 ha field crops using drip irrigation system. A "headworks" with 200 $m^3\ h^{-1}$ flow rate filter can service about 60–80 ha of field crops. Therefore, there are between 10,875 and 14,500 filters used for drip irrigation systems in XJPCC alone. One of the most common types of filter used in drip irrigation systems is the self-cleaning screen filter. The performance of screen filters used in XJPCC is different from elsewhere in the world due to its different construction, different flow rate and the fact that particles present in the water are mainly sand. The structure of screen filter used in XJPCC is usually vertical whilst most others are horizontal. The flowrate of screen filters in XJPCC is also relatively higher than others, around 150–220 $m^3\ h^{-1}$ for XJPCC whilst not more than 10 $m^3\ h^{-1}$ elsewhere (Duran-Ros, Arbat, Barragá, Ramírez de Cartagena, & Puig-Bargué, 2010; Puig-Bargue, Barraga, & Ramıŕez de Cartagena, 2005b).

Because filters are the key equipment of drip irrigation, there were several experimental studies on their performance (Liu, Zheng, Liu, & Zong, 2010, 2012; Zong, Liu, Liu, & Zheng, 2012a, 2012b). The performance of a filter can be defined by the head loss, the period required before cleaning, the time required to clean the filter and the type of mechanical and hydraulic problems encountered (Ravina et al., 1990).

Filter performance in drip irrigation systems using effluents has also been studied by a number of authors (Adin & Elimelech, 1989; Capra & Scicolone, 2007; Duran-Ros, Puig-Bargué s, Arbat, Barraga' n & Ramıŕez de Cartagena, 2009a, 2009b; Puig-Bargué s, Barraga' n & Ramıŕez de Cartagena, 2005a, 2005b; Ravina et al., 1997; Ribeiro, Paterniani, Airoldi, & Silva, 2008; Tajrishy, Hills, & Tchobanoglous, 1994). Although previous studies have provided some models and experiments showing the results of the head loss of screen filters, they have not provided an effective method for calculating head loss for different screen filters.

The equations available to describe the performance of filters used in drip irrigation systems have been mainly developed for disc, hydrocyclone, screen and sand filters. Equations used traditionally to study filtration require the use of parameters related to filtration cake characteristics which are difficult to estimate because of variations that occur during any filtration cycle (Adin & Alon, 1986; McCabe, Smith, & Harriott, 2001). Dimensionless analysis and dimensionless parameters are useful tools for the analysis of this type of hydraulic problem. Thus, Arno' (1990) used this technique with screen filters and uniform size particles and obtained two dimensionless groups that characterised the filtration process. Yurdem, Demir, and Degirmencioglu (2008, 2010) developed a mathematical model to predict head losses using tap water in disc and hydrocyclone filters for drip irrigation systems using dimensional analysis. Puig-Bargués et al. (2005b) found a head loss equation for disc, screen and sand filters working with effluents and adjusted it to provide satisfactory performance using experimental data. Duran-Ros et al. (2010) assessed the validity of the equations developed by Puig-Bargués et al. (2005b) and Yurdem et al. (2008) with new data, and developed a new equation for disc, screen and sand filters, which included head loss, filtration velocity, concentration of total suspended solids in the filter influent, water density and viscosity, and inside diameter of the inlet and outlet pipes.