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PORTABLE SAND FILTER FOR SMALL DRIP IRRIGATION SYSTEMS

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1 ABSTRACT

Filters in drip irrigation systems are fundamental to ensure effective control of water quality and to reduce clogging of emitters. Current study aims at constructing a low cost portable sand filter for small localized irrigation systems (up to 1.0 ha) and at determining its head loss due to flow. Tests were carried out in the Hydraulic Laboratory of Biosystems Engineering Department of Agriculture School “Luiz de Queiroz”, University of São Paulo. Magnetic-induction Conaut Krohne model IFS 4000 w/6 with IFC 090 D signal convert of discharge, reading range between 0 and 90 $m^3.h^{-1}$ and 99% precision, was used for flow rate measurements. Pressure loss at each observation point was determined indirectly by two differential pressure gauges with a mercury column. A set of 20 flow readings was performed in three replications. Results showed that maximum filter discharge complied with ASAE guidelines and the cost of materials for manufacture of the filter was U$ 382.15. Linear mathematical model adequately describes the loss of pressure of the sand filter due to flow variation. Rates of minimum and maximum flow recommended range between 0.0257 $m^3.h^{-1}$ and 0.556 $m^3.h^{-1}$, and thus may satisfy small trickle irrigation projects.

Keywords: Filtration, water quality, head loss, flow rate.

2 RESUMO

OLIVEIRA, C. F. de; TEIXEIRA, M. B.; RAMOS, A.; SILVA, R. M. da; RIBEIRO, P. H. P.; FRIZZONE, J. A.
FILTRO DE AREIA PORTÁTIL PARA PEQUENOS SISTEMAS DE IRRIGAÇÃO POR GOTEJAMENTO

Nos sistemas de irrigação localizada, os filtros são as peças fundamentais para garantir o controle efetivo da qualidade da água e, consequentemente, reduzir a obstrução dos emissores. Dessa forma, o presente trabalho teve como propósito a construção de um filtro de areia portátil, com baixo custo de fabricação para pequenos sistemas de irrigação localizada (áreas até 1,0

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ha), e a determinação de sua perda de carga em função da vazão. Os ensaios foram conduzidos no Laboratório de Hidráulica do Departamento de Engenharia de Biossistemas da Escola Superior de Agricultura "Luiz de Queiroz", Universidade de São Paulo. Para as leituras de vazão, utilizou-se um medidor magnético indutivo Conaut-Krohne, modelo IFS 4000 W/6, com conversor de sinal IFC 090 D, com faixa de leitura de 0-90 $m^3.h^{-1}$ e precisão de 99%. A perda de carga em cada ponto de leitura foi determinada, indiretamente, utilizando dois manômetros diferenciais com coluna de mercúrio. Foram feitas 20 leituras de vazão em três repetições. Os resultados mostraram que a vazão máxima do filtro 0,556 $m^3.h^{-1}$, atendeu a recomendação proposta pela ASAE e que o custo dos materiais para a confecção do filtro foi de R$ 1.505,09. O modelo matemático linear descreveu adequadamente a perda de carga do filtro de areia em função da variação da vazão. Os valores de vazão mínima e da vazão máxima recomendada ficaram na faixa de 0,0257 $m^3.h^{-1}$ a 0,556 $m^3.h^{-1}$, permitindo atender pequenos projetos de irrigação por gotejamento.

Palavras-chave: Filtração, qualidade da água, perda de carga, vazão.

3 INTRODUCTION

The clogging of emitters in irrigation is caused by mineral and organic particles and by chemical precipitates that impair hydraulic performance and thus reduce the components´ useful life. Also increases maintenance problems and consequently the system´s operational costs by reducing uniformity in water distribution and a fall in irrigation efficiency (RIBEIRO; COELHO; TEIXEIRA, 2010).

The amount of sediments in irrigation water affects negatively the adequate performance of irrigation systems. Choosing the filtration system and its capacity is highly important since it may avoid frequent cleaning and replacement of components. According to Ravina et al. (1992), small irrigation projects should have high efficient filtering systems.

Filter installation in small irrigation systems to avoid clogging of emitters in irrigation causes variations in the system´s hydraulic performance after a certain run of time. When discharge flowing to the system passes through the filter, it reduces filtration due to the adherence of suspended solid matter to the filter. In fact, a layer of solid particles is formed on the upper part of the sand, with high discharge loss and decrease of the available discharge in the filter. It affects pressure gauge height and the system´s flow rate (RIBEIRO et al., 2005; OLIVEIRA, 2005; MESQUITA, 2012).

Zeier e Hilss (1987) state that besides the factors that affect the filter´s performance, pressure fall should also be taken into account due to the materials adhered to the filter.

According to Testezlaf (2008), filters with a porous medium, especially those with sand, are recommended when water is contaminated with organic particles and algae. Its adequate measurements and operation are essential to reduce clogging of emitters.

Dehghanisanij et al. (2004) evaluated the impact of biological contaminants in drip clogging and concluded that sand filter was more effective in the removal of these agents.

In the experimental analysis of the disc filter processes, Oliveira (2005) found that the use of small localized irrigation is growing in Brazil owing to the scantiness of water resources and the need to save water during the irrigation process. These factors trigger the development of materials and equipments that improve on small irrigation systems (PATERNIANI et al., 2011).

Since very few research works have been published on these filters and technical information on their appropriate operation in Brazilian conditions is insufficient, with limited technical assistance, the equipments´ functions are not fully achieved and farmers become unsatisfied with the low performance of irrigation systems. To make matters worse, the initial costs inhibit the use of the equipment and producers seek other filter types for alternatives, albeit lacking the same efficiency and application.

Current research discusses the construction of a low cost portable sand filter and determines its head and flow loss for small localized irrigation projects.

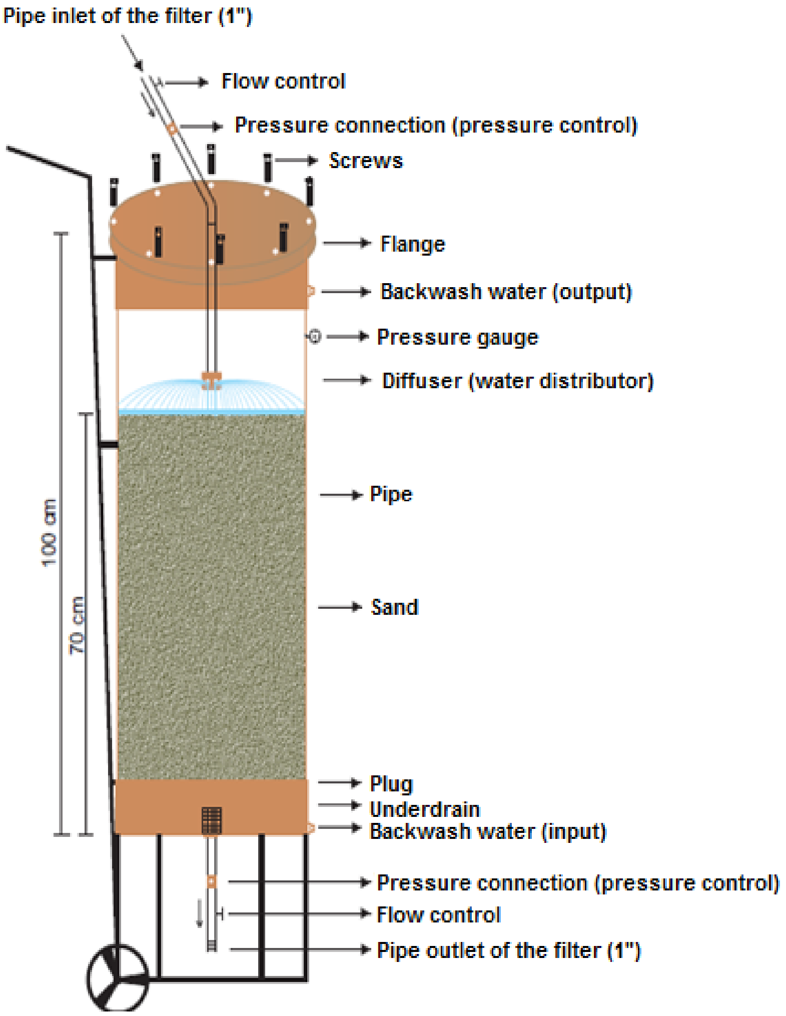
4 MATERIALS AND METHODS

The portable sand filter was developed and characterized in the Hydraulic Laboratory of the Biosystems Engineering Department of the School of Agriculture “Luiz de Queiroz” - ESALQ/USP, in Piracicaba SP Brazil.

The basic structure of the portable sand filter comprised a 200 mm-PVC pipe, diameter 8” and 1 m height. An 8” cap was placed in the lower section of the filter close to the diffusers to prevent sand passing to the irrigation drip lines. A flange with a screwed joint was placed in the upper section of the filter to fix adequately the filter´s internal parts. PVC entrance and exit 1” pipes, water entrance and exit 1” registers were employed and pressure gauges for the display of head loss were respectively installed at the entrance and exit.

A pressure gauge was installed in the upper section of the filter structure to measure the internal pressure in the backwashing of the sand filter, coupled to two upper and lower plugs, 1” diameter, for backwashing of the filter, when required (Figure 1).

Figure 1. A cross-section sketch of a portable sand filter



Source: Cleomar Ferreira de Oliveira.

A water flow diffuser was developed and adapted at the end of upper section of the 1" pipe, between the sand layer and the flange, the place where water is distributed in the filter, at a height of 0.18 m above the sand layer, following equation 1.

$$Q = Cd.S.\sqrt{2.g.H} \quad (1)$$

in which:

Q – flow rate, $m^3.s^{-1}$;
Cd – coefficient of discharge (according to the filtrating material employed – Table 1);
S - area, m^2;
g – acceleration of gravity, 9.81 $m.s^{-2}$;
H – pressure gauge, m.

A 0.15 m space for the expansion of the filtering bed during backwashing lies between the water flow distributer and the filtrating layer. The sand filter was fixed with screws and metal bands on a two-wheel carriage for portability sake and for its adaptation to a small irrigation system (up to 1.0 ha) with a flow rate of up to 0.556 $m^3.h^{-1}$ per irrigated area.

A KSB motor pump (Hydrobloc P1000) connected to a 500 L-PVC reservoir, was used for the application of water. A 32 mm-pipe conducted water from the reservoir up to the hydraulic pump. Hydraulic network of the hydraulic pump up to the sand filter´s entrance and exit consisted of 25 mm-PVC pipes and 1” hydraulic joints (curves, nipples, registers etc.).

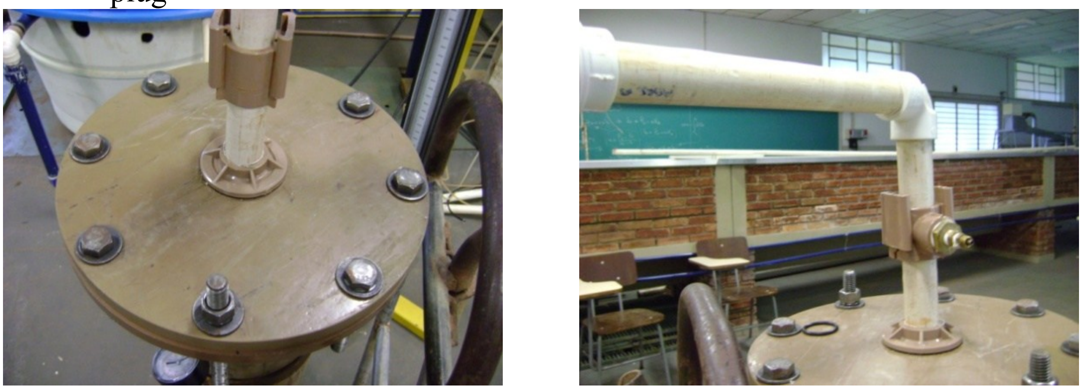
Magnetic induction flow rate gauge, Conaut – Krohne, IFS 4000 W/6, with signal converser IFC 090 D and reading range between 0 and 90 $m^3.h^{-1}$ and 99% precision, was employed for measuring the flow rate. Figures 2 to 7 show the portable sand filter´s construction and assay details.

Figure 2. Details of the construction of the portable sand filter: a) position of the sand filter fixed on the carriage ready for insertion in the irrigation system; b) carriage position for the transport of sand filter

a b

Source: Cleomar Ferreira de Oliveira.

Figure 3. Details of the construction of the portable sand filter: a) sealing system by flanges, screws and bolts (upper section), b) supply system (upper section) and upper pressure plug



a b

Source: Cleomar Ferreira de Oliveira.

Figure 4. Details of the construction of the portable sand filter: a) flow rate control gauge after passing through the sand filter and pressure plug in the pipe´s lower section; b) a 90° curve for backwashing pipe connection (lower section of the sand filter)

a b

Source: Cleomar Ferreira de Oliveira.

Figure 5. Details of the construction of the portable sand filter: a) flow rate gauge connected to the motor pump system and to the upper part of the sand filter; b) flow rate gauge with a range between 0 and 90 $m^3.h^{-1}$ and 99% precision

a b

Source: Cleomar Ferreira de Oliveira.

Figure 6. Portable sand filter´s flow rate assay: a) upper view of the mercury gauge and its connections employed for monitoring head loss of the sand filter during the trial; b) the lower section of the mercury gauge used in the trial

a b

Source: Cleomar Ferreira de Oliveira.

Figure 7. Portable sand filter´s flow rate assay: a) reservoir (500 L); motor pump system (1.5 cv); portable sand filter; mercury gauge (background); b) supply pipes (upper part) connected to flange screwed to the filter structure and back supply locked to the filter base (cap locked to the filter structure) and to the motor pump system used in the trial

a b

Source: Cleomar Ferreira de Oliveira.

Table 1 shows a list of materials for the construction of a sand filter and its costs.

Table 1. List of materials for the construction of a portable sand filter and costs

Material	Quantity	Cost per unit (R$)	Total cost (R$)
PVC pipe 8”	1	480.00	480.00
Cap 8”	1	120.00	120.00
Flange 8”	1	170.00	170.00
Diffuser	1	280.00	280.00
L-pipe joint 1”	4	1.97	7.88
T-pipe joint 1”	1	3.63	3.63
Connection 1”	2	6.69	13.38
Adapter	2	1.25	2.50
Nipple 1”	4	0.95	3.80
Gauges 1”	2	7.35	14.70
Screws + washers	16	1.95	31.20
Metal bands	2	11.00	22.00
Carriage	1	200.00	200.00
Bourdon gauge	2	78.00	156.00
Total			1505.09

Source: Oliveira, et al. (2015).

The height of the filtrating layer (sand) was 0.70 m, with a filtrating area of 0.023 m^2, according to granulometry classification and its meshes (Table 2), suggested by Testezlaf (2008).

Table 2. Classification of filtrating material by particle size corresponding to a determined number of meshes

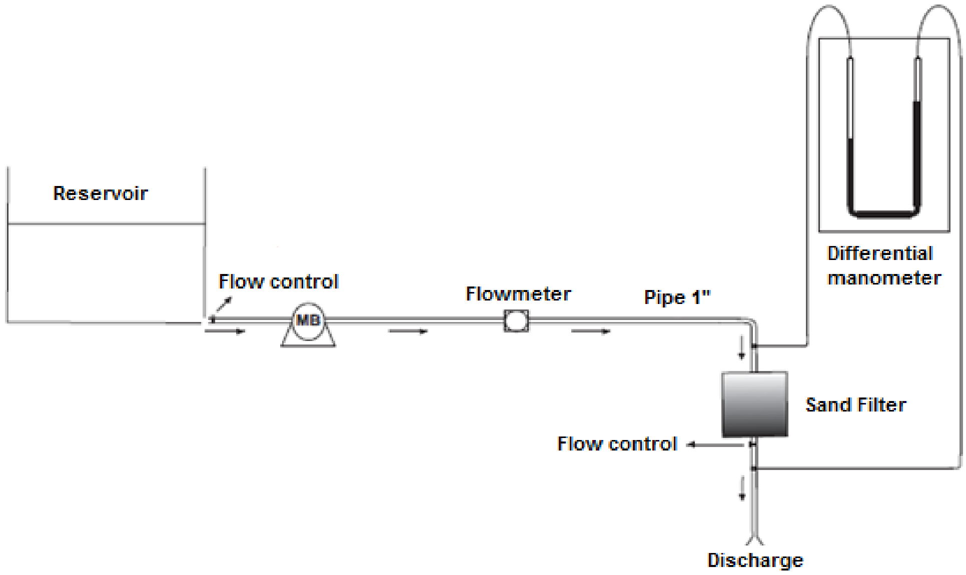
Material	Class N	ϕ Effective (mm)	ϕ pore (mm)	Meshes	Removed particles (µm)	Removed material
Medium-sized sand	8	1.50	0.214	70	> 160	Physical
Medium-sized sand	11	0.78	0.111	140	> 80	Physical–chemical
Fine sand	16	0.66	0.094	170	> 60	Physical–chemical
Very fine sand	20	0.46	0.066	230	> 40	Physical-chemical–biological
Silt	30	0.27	0.039	400	> 10	Biological

Source: Testezlaf (2008).

Twenty flow rate readings in three different analyses (replications) were performed to determine the head loss due to flow rate, with the above-mentioned equipments and two mercury column differential gauges and 1” plugs for assay monitoring (Figure 8).

Maximum rate flow in the trial for sand filter complied with recommendations by ASAE (1993), with flow rates between 10 and 18 L.s^{-1}.m^{-2}.

Figure 8. Experimental cross-section to determine head loss due to circulating flow rate



Source: Cleomar Ferreira de Oliveira.

So that backwashing and cleansing of sand filter could be performed, the irrigation system was switched off and the water entrance-exit by pipes and plugs 1" was inverted. Although there is no fixed rule on the precise moment for filter cleansing, state that filter backwashing is required when a 100 kPa loss occurs (NAKAYAMA; BUCKS, 1991).

Source of water used in the tests was the water treatment station of the ESALQ/USP Piracicaba SP Brazil. It was analyzed following methodology by APHA-AWA-WEF (2005) (Table 3).

Table 3. Analysis of water from the Hydraulic Laboratory of ESALQ/USP used in the experiment

Parameter	Unit	Result
Alkalinity ($CO_3^{2-} + HCO_3^-$)	mg.L^1	35.8
Chloride (Cl^-)	mg.L^1	33.9
Phosphorus (P)	mg.L^1	0.05
Ammoniacal Nitrogen ($N\text{-}NH_3$)	mg.L^1	0.11
Sodium (Na^+)	mg.L^1	44.0
Potassium (K^+)	mg.L^1	7.1
Calcium (Ca^{2+})	mg.L^1	33.2
Magnesium (Mg^{2+})	mg.L^1	9.2
Iron (Fe^{2+})	mg.L^1	0
Aluminum (Al)	mg.L^1	0
Apparent color	PtCo	4
Turbidity	FTU	4
Suspended sediments	mg.L^1	6.0
Electrical conductivity (EC)	mS.cm^{-1}	0.37
pH		7.5
Carbon dioxide (CO_2)	mg.L^1	1.9
Acidity ($CaCO_3$)	mg.L^1	6.5
Total hardness ($CaCO_3$)*	mg.L^1	120.6

*Total hardness was calculated on the equivalent of calcium carbonate ($CaCO_3$). *Standard methods for the examination of water and wastewater*. American Public Health Association - APHA-AWA-WEF (2005).
Source: Oliveira, et al. (2015).

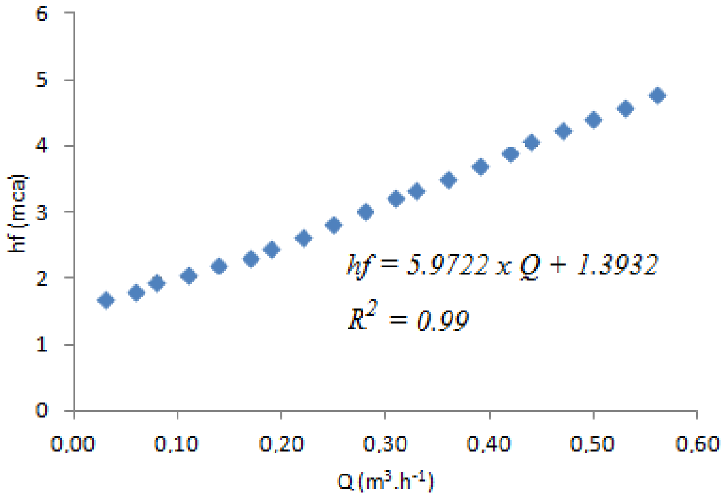
Statistical analyses were undertaken with SAS 8.02 (SAS INSTITUTE, 2001) by the Generalized Linear Model (GLM) procedure. Complete randomized design was employed, with tests "F" for analyses of variance and regression.

5 RESULTS AND DISCUSSION

Trials with the sand filter verified the hydraulic performance by determining head loss due to flow rate. When the experimental rates of head loss due to flow rate were known, curves were adjusted for a mathematical model that would display a significant correlation rate among the variables. According to Testezlaf and Ramos (1995), knowledge of this characteristic gives the correct dimension of the filter for each condition of the project.

Figure 9 illustrates the curve adjusted to rates of head loss of sand filter with meshes ranging between 140 and 170.

Figure 9. Head loss (*Hf*) due to flow rate (*Q*) for the sand filter and the respective equation for head loss and R^2



Source: Oliveira, et al. (2015).

Equation $hf = 5.9722 \times Q + 1.3932$ for head loss of the sand filter has been described by a linear mathematical model so that variation in head loss in the sand filter due to the circulating flow rate could be shown (Equation 2):

$$hf = \beta_o Q + \beta_1 \quad (2)$$

in which:

hf = Head loss in sand filter, m;

Q = Flow rate through the filter, $m^3.h^{-1}$;

β_o = coefficient of permeability associated with head loss and a-dimensional unit flow rate;

β_1 = coefficient of permeability characteristic of the a-dimensional filtrating material.

Although determination coefficient is not very high, adjustment was significant for $p<0.001$ and indicated a strong relationship of the linear model between the variables flow rate and head loss.

Mesquita et al. (2012) showed that the mathematical exponential function represented best the physical phenomenon of head loss due to flow rate for three sand models, with clean water and without the filtrating medium, manufactured in Brazil.

Table 4 shows the operational characteristics of the sand filter developed.

Table 4. Characteristics of the portable sand filter developed in lab conditions

Model	Filtered area	N. of meshes	Recommended minimum rate flow	Recommended maximum rate flow	Entrance/exit diameter	Specific head loss
	(m^2)		($m^3.h^{-1}$)	($m^3.h^{-1}$)	(mm)	(kPa)
Sand	0.023	140 - 170	0.0257	0.556	25	47.754

Source: Oliveira, et al. (2015).

During the trials, specific head loss in the clean filter (Table 4) was higher than that recommended for sand filters. Mesquita et al. (2012) reported that the hydraulic performance of the three sand filter models underwent modifications in the standard operation due to internal structure type, diffuser plate and drainage. In the case of empty filters, the internal components of Filter 1 caused higher head loss rates for the same rates of the hydraulic flow when compared to Filters 2 and 3.

Puig-Bargués; Barragán; Cartagena (2005) remark that high internal pressure in filters may deform the biological particles retained in the filtering medium. They may pass through the filter and reduce the efficiency of the filtering system.

Oliveira (2005) showed that the installation of an automatic backwashing system is highly important for the improvement of the filtering system and of practicality in cleaning.

Low rates in entrance pressure for more efficient backwashing should be obtained for a decrease in energy consumption (DURAN-ROS, 2009).

Analysis of variance showed that the linear model justifies the hydraulic performance of the sand filter, with a probability significance of 0.01 (Table 5).

Table 5. Analysis of variance for collected data

Variation source	Sum of squares	Freedom degree	Mean square	F	Pr > F
Regression	55.09039	1	55.09039	351.29	<.0001
Error	9.09584	58	0.15682		
Total	64.18623	59			

Source: Oliveira, et al. (2015).

Table 6 shows rates of confidence intervals for parameters β_o and β_1 of regression analysis at 95% probability.

Table 6. Confidence intervals for analysis of regression parameters

Coefficients	Rate	Standard error	t rate	Confidence interval at 95%
β_0	1.39203	0.10576	13.16131	1.18035 ↔ 1.60372
β_1	5.97489	0.31785	18.79780	5.33873 ↔ 6.61104

Source: Oliveira, et al. (2015).

6 CONCLUSIONS

Conclusions on assay results with sand filter are:

a) The number of meshes of the portable sand filter ranged between 140 and 170.
b) Rates of minimum and maximum flow recommended range between 0.0257 $m^3.h^{-1}$ and 0.556 $m^3.h^{-1}$, and thus may satisfy small trickle irrigation projects.
c) Linear mathematical model described head loss caused by circulating flow rate in the sand filter.
d) Specific head loss was 47.75 kPa.

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