

Application of optical properties in water purification quality testing

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Abstract

The current study was performed to test filtration media system performance on quality of water purification and to evaluate optical properties, such as reflection, transmission and absorption intensities for filtered water using a spectrophotometer operating in the range 350–400 nm. Head losses through filtration system at the experiments were equal to 20, 40, and 60 kPa. With the progress of the filtration process and increase in different head loss (from 20 to 60 kPa), both the content of total suspended solids and turbidity in optical properties intensities for filtrated water increased, together with the water cloudiness. It is shown that the intensity of optical properties can be considered a reliable indicator that to determine the need for backwashing of the filtration system.

Key words: filter backwashing, media, removal efficiency, total suspended solids, turbidity

Highlights

- Local gravel samples are high quality and easy to use in the Egyptian natural environment.
- Gravel or sand media filters are particularly suitable for water with a high TSS content.
- Optical properties are known to be the best indicator for filtering backwashing.

LIST OF ABBREVIATIONS

Tu	Turbidity
TSS	Total suspended solids
Ref	Reflection
Trans	Transmission
Abs	Absorption
fw	Filtered water
Er	Removal efficiency
hl _m	Head losses
C _c	Curvature coefficient

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INTRODUCTION

Micro-irrigation systems (MIS) (surface drip irrigation and subsurface drip irrigation) are an appealing choice for saving water in Egypt, where water resources are limited (Puig-Bargués *et al.* 2010). The emitter can discharge a large amount of sediment particles, depending on the hydraulic shear force (Feng *et al.* 2018).

Filter clogging is a substantial problem, in the case of surface water sources (open channels, rivers or lakes) for these systems where the irrigation water usually is not found in its pure state, but mostly with foreign solid particles and other impurities, especially when treated wastewater of low quality is used because it contains high concentrations of dissolved and suspended solids (Bucks *et al.* 1979; Ravina *et al.* 1997). Solid particles, mainly including impurities, non-organic matters (trash, silt, sand, leaves, fine clay and rust dust), organic matter (algae, bacteria and protozoa), and other solid contaminants, are present in irrigation water (Eurodrip 1999; Zhou *et al.* 2017).

The total amount of suspended solids in Alabaster Misr Bank water samples was less than that of Ward El-Nile Zaffaran at the same operating pressure. While evaluating the efficiency of the dripper using suitable filtration media for the first filter, it was found that 94.73, 89.55 and 79.65% of the local basalt emission uniformity was excellent, good and fair, respectively, and 95.84, 89.66, and 79.57% of the second Alabaster Misr Bank filter at 20, 40 and 60 kPa EU was excellent (Hassan *et al.* 2019). The filtration is an important process that can help avoiding physical clogging of MIS (Kuslu & Sahin 2013; Bounoua *et al.* 2016). It is the physical management that is used to maintain the closed irrigation system at a satisfactory performance (Oron *et al.* 1979; El Awady *et al.* 2001). Screens, discs and sand-gravel media are the main filter types used in MIS. Sand or gravel filtering followed by screen and disc filters (Puig-Bargués *et al.* 2005a) are those that provide MIS with better protection (Capra & Scicolone 2004; Hamoda *et al.* 2004; Burt & Styles 2007; Trooien & Hills 2007) because they exhibit the highest removal efficiency (E_r) for total suspended solids (TSS) organic compounds, phosphorus and microorganisms (Naghavi & Malone 1986; Haman *et al.* 1994; Capra & Scicolone 2007; Dalahmeh *et al.* 2012).

In media filters, solids (very fine sand, silt, and clay particles, algae and bacteria) are trapped by the particles of gravel or sand where particle capture is controlled by both physical and chemical mechanisms (Adin & Alon 1986). This process decreases the rate of water flow through the filtration system because the system is clogged and must be cleaned in order to recover operating conditions through a backwashing procedure (Shock 2006). Most sand or gravel filters are cleaned automatically by backwashing frequently (Pitts *et al.* 1990; Nakayama *et al.* 2007). Automatic backwashing can be managed by an operating time and/or by passing water flow at the total pressure drop across the filters of 50 kPa for sand or gravel filters and 40 kPa for screen and disc filters. Usually, a backwashing time from 20 to 180 s is used (Ravina *et al.* 1992; Elbana *et al.* 2012). Both options allow for easy system automation (Duran-Ros *et al.* 2009). Unfortunately, during the filtration process, large and interconnected pores called 'Rat Holes' can form in the media leading to decreasing filter performance (Nakayama *et al.* 2007).

Remote sensing (RS) is usually restricted to methods that detect and measure electromagnetic energy, including visible and non-visible radiation that interacts with surface materials, and an idea of providing RS by deriving information on optical properties and the concentrations of substances from variations in the color of the water. The variables of water quality; that is, TSS, T_u , the content of humic substances, chlorophyll, and so on, could be estimated by a variety of techniques for remote and optical sensing (Morel & Prieur 1977; Dekker 1993; Bukata *et al.* 1995; Rev-Herlevi 2002; Arst 2003; Pozdnyakov & Grassl 2003; Reinart *et al.* 2004; Gallegos *et al.* 2008), by interpreting the received radiance at different wavelengths (Yentsch 1984). TSS is the regulatory positively or negatively correlated indicator of 'suspended sediment pollution' (Wang *et al.* 2010). Besides, water clarity or T_u is a direct measure of visible distance through water. It is an important indicator of

the presence of sediments in the water column, and a useful parameter for determining the content of TSS and dissolved materials (Davies-Colley & Smith 2000). Therefore (Ceccato *et al.* 2001; Doxaran *et al.* 2002; Dolinar 2014), using visible and near-infrared (NIR) wavelength satellite data and multi-spectral optical sensors and visible to infrared optical sensors, the water composition can be determined in terms of Tu and TSS by measuring part of the visible light transmitted through them in a straight line between the light source and the light receiver, or part of the visible or infrared light that is reflected (Williamson & Crawford 2011).

Optical multispectral sensors give reliable and accurate readings for TSS in the range of 0 to 500 mgL⁻¹ (Al-Yaseri *et al.* 2013). In addition, it was concluded (Hassan *et al.* 2020) that 632.8 nm is a suitable wavelength to study the optical properties of filtrated water over local basalt media under different head losses through filter media using a He-Ne laser.

Elhegazy & Eid (2020) introduced a review of the research that covered grey-water management. It provided perspectives on grey-water context in order to frame the breadth and multiple dimensions it encompasses, to summarize recent activities on selected relevant topics, and to highlight possible future directions in research and implementation.

PROBLEM STATEMENT AND RESEARCH OBJECTIVE

There is a deficiency in the use of modern technology in the management of irrigation systems, including the filtering system used, caused by the lack of reliable data on optical properties of filtrated water, which is a motivation of the work performed.

MATERIALS AND METHODS

Current assay was conducted between July and December 2019, at the National Irrigation Laboratory of Agricultural Engineering Research Institute (AEnRI), ARC, and the laboratory of laser applications in agricultural engineering at the National Institute of Laser Enhanced Science (NILES), Cairo University, to detect optical properties for filtrated water under various operating conditions, using a spectrophotometer. The filter unit was the main component of the experiment. It had a cylindrical shape with a diameter of 600 mm, height of 900 mm, depth of 600 mm and surface area of 0.471 m², maximum volume of 33.9 m³ h⁻¹, and inlet and outlet links with a diameter of 50 mm.

Local basalt gravel media had a bulk density (ρ) of ≈ 1.68 gcm⁻³, porosity (n) of 43.41%, and pH and CaCO₃ values of 7.3 and 0.5% respectively. Local basalt gravel was sourced from the local market (Abo-Zaable, Qaibia government) and mainly used for building construction. For this substance, effective diameters (d_e) (size opening that will pass 10% by dry weight of a representative sample of the filter material) were 1.19, 1.75, and 2.32 mm for d_{10} , d_{50} , and d_{60} respectively. The particle size parameters; that is, the uniformity coefficient (C_U) (ratio of the size of opening that will pass 60% of the sand to the size of opening that will pass 10%) and curvature 114 coefficients (C_c) were 1.94 and 1.11 respectively.

For filtration experiments, a filtration system with three-filter units was used. This consisted of a 22 kW pump, with a pressure head of 550 kPa (approximately 5.5 bar) and a flow rate of about 100 m³ h⁻¹, which injected Nile water from a concrete reservoir with a capacity of 8 m³. Each filtration unit had a pressure gauge and valve at the inlet and outlet of the system to monitor head losses through the hl_m filter bed (to increase hl_m the inlet flow volume to the filtration system was increased and the outlet volume of the inlet flow decreased). The experimental setup allowed that all filters were operating at a time; experiments were carried out, for 80 h, for 4 h day⁻¹. Experimental measurements to assess filter performance were carried out at the beginning of each 20 h under three hl_m (20, 40, and 60 kPa). The effectiveness of a filter (removal efficiency E_r was computed by measuring the ability of

the gravel media filter to remove suspended particles and turbidity from the inlet water. The evaluation of the E_r followed the measurements of the TSS and T_u of water samples before and after the filter unit. Turbidity (T_u) was measured using an HI 93703 handheld turbidity meter (Hanna Instruments, Woonsocket, RI, USA), and TSS were determined in the laboratory by the gravimetric method. Forty samples (8 samples \times five replicates) were taken periodically at the filter inlet and outlet to calculate the average value through the whole experiment. Additionally, E_r was calculated according to the equation as seen below (ASAE 2005).

$$E_r = \left(\frac{Y_i - Y_o}{Y_i} \right) \times 100$$

where, E_r (%) is the removal efficiency for a physical parameter with Y being TSS (mgL^{-1}) or T_u (FNU) – Formazin Nephelometric Units – Y_i being the physical parameter value before filtering and Y_o its value after filtration.

In addition, the spectrophotometer (Ocean Optics USB650) was used to detect suitable visible wavelength within the range ≈ 350 – $1,000$ nm to measure the peak values for a number of optical parameters. The measurements were of reflection (Ref), transmission (Trans) and absorption (Abs). All samples were made of particle suspensions contained in a 1-cm quartz cuvette that was placed inside the integrating sphere. The visible light was focused on one side of the quartz cuvette containing the sample. The emitted light was collected perpendicularly via a fiber optics connector (SAM 905 to single-strand optical fiber 0.22 NA). Acquisition and analysis of the spectra obtained from the spectrophotometer system were accomplished using the commercial SpectraSuite software and further processed using computer software.

RESULTS AND DISCUSSION

The only parameters whose removal efficiency differed, caused by the different hl_m , were TSS (mgL^{-1}) and turbidity T_u (FNU). This was in agreement with the previous experiments with Nile water (Adin & Elimelech 1989; Ravina *et al.* 1997; Elbana *et al.* 2012), using the same gravel filter.

- They have achieved reducing 'TSS' concentration sharply from 249.6 before filtration to 51.66, 115.06 and 129.29 mgL^{-1} after filtration and E_r was about 79.3, 53.9 and 48.2% at $hl_m \approx 20, 40$, and 60 kPa, respectively.
- 10 h of the filtration system operation proved that sand or gravel filtration is the most efficient for reducing and removing TSS.
- The efficiency of suspended solids was reduced from 11.4 to 48.0% using the sand filter filled with different media.
- TSS concentration at fw increased slightly with increasing accumulated T (h) at different hl_m until the end of the experiment. The concentration of TSS in fw was increased from 51.67, 115.06, and 129.29 mg L^{-1} after 10 h from the experiment beginning to 163.49, 226.14, and 268.81 mgL^{-1} at the end of the experiment (80 h) under $hl_m \approx 20, 40$, and 60 kPa respectively (Figure 1). In addition, the outlet concentrations of 'TSS' increased logarithmically, linearity at $hl_m \approx 20, 40$, and 60 kPa respectively, from 10 to 80 h. So, it can be concluded that the solids accumulation in the filter beds increased logarithmically as the filtration test period progressed.
- Adin & Alon (1986), and Hassan *et al.* (2020) observed the same results. Figure 2 presents the turbidity T_u removal efficiency, E_r (%), computed using Equation (1). The values were measured at the filter inlet and outlet (just before and after filtering).
- The filter achieved a reduction of about 82.4, 62.1, and 54.79% of T_u in the first 10 h of the experiment at $hl_m \approx 20, 40$, and 60 kPa respectively. These are in agreement with those obtained by

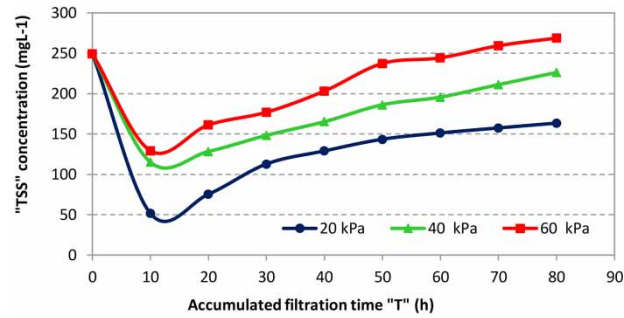


Figure 1 | Behavior of TSS concentration during filtration process progress.

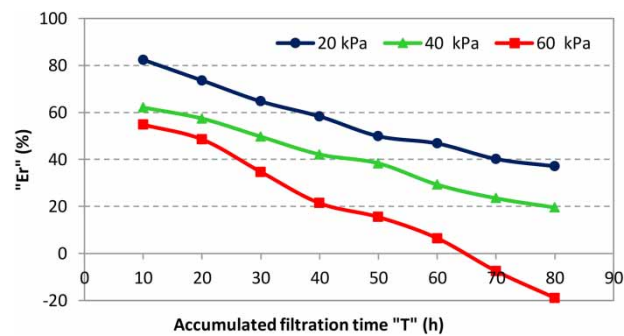


Figure 2 | Behavior of Er for Tu during the filtration process, progress under different h_{lm} (kPa).

(Nakhla & Farooq (2003)). Then, Er for Tu tended to decrease at fw with the increase in the filtration test period. It had a negative relation with accumulated experiment time T (h).

- These relations were exponential at $h_{lm} \approx 20$ kPa and linearity with $h_{lm} \approx 40$ and 60 kPa, with correlation coefficient (R) of 0.998, 0.997, and 0.9964. The porous gravel media filter showed turbidity removals of 37.1, 19.55, and -18.9% at the end of the experiment (after 80 h). These results could be in agreement with Tripathi *et al.* (2014), Solé-Torres *et al.* (2019).
- Generally, there was less Tu after the gravel filter at different h_{lm} than there was before for all experiments except after ≈ 65 –80 h with $h_{lm} \approx 60$ kPa. Both Tu and TSS concentrations at the fw were larger than at the inlet, which tended to negative values for Er. Besides, these mean that the filter was clogged, probably due to filtration cake detachment as mentioned by Neis & Tiehm (1997) and Puig-Bargués *et al.* (2005b). Figure 3 shows the regressions plateau between Tu (FNU) and TSS (mg/L). Furthermore, Tu had a non-linear correlation with TSS. It was power-related with TSS at $h_{lm} \approx 20$ kPa, and exponential – related at $h_{lm} \approx 40$ and 60 kPa.

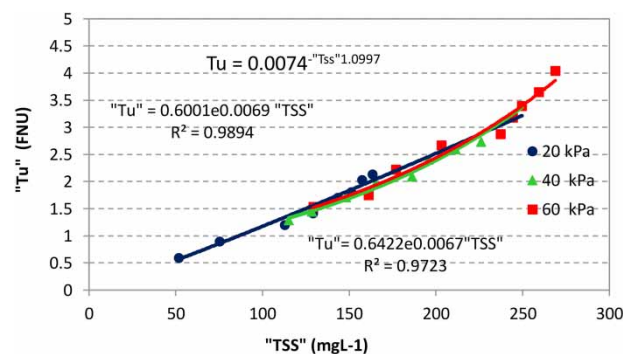


Figure 3 | Correlation between the Tu and TSS at different h_{lm} .

Similar results were demonstrated by Wu *et al.* (2014), who indicated that height agreement was observed between the Tu and TSS. Water clarity was always 220 positively correlated with TSS (Bucks *et al.* 1979; Davies-Colley & Smith 2000; Wang *et al.* 2010).

The optical properties for fw were scanned in visible light wavelength from 350 to 1,000 nm. In addition, the curves of optical properties; that is, Ref, Trans, and Abs, (%) were occurring in the range 350–400 nm. The recorded spectra for some samples of fw with different TSS concentrations (51.6, 115.06, and 268.8 mg L⁻¹) under various operating procedures h_{lm} (20, 40, and 60 kPa) are displayed in Figure 4(a)–4(c). After 10 h of running the filters, the TSS concentration reached 51.8 and 115 mgL⁻¹ with Er for TSS \approx 79.3 and 53.9% at h_{lm} 20 and 40 kPa. It follows that the Ref intensity range for fw was decreased from 55.43–99.48% with three peaks at 361, 371, and 378 nm, to 47.07–56.94% with one small peak at 355 nm. The Trans intensity range decreased from

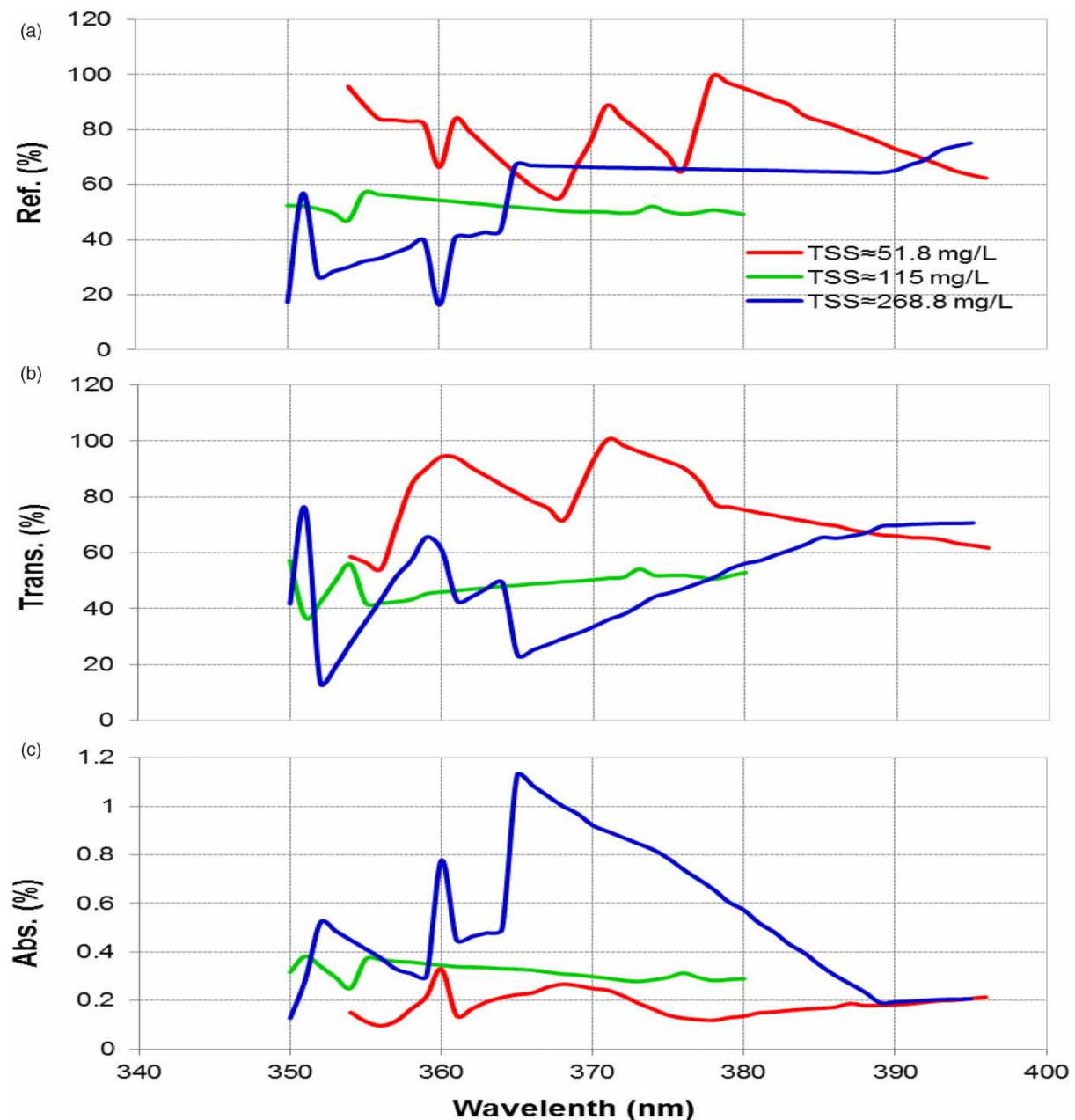


Figure 4 | Optical properties for fw at different TSS concentrations.

54.22–99.8% with two peaks at 360 nm, and 371 nm, to 36.87–57.2% with 354 nm. Whereas, the Abs intensity range for fw with a higher TSS increased from 0.096–0.267% with one peak at 360 nm for $hl_m \approx 20$ kPa to 0.251–0.382% with one peak also at 355 nm for $hl_m \approx 40$ kPa.

Meanwhile, at the experiment end, with $hl_m \approx 60$ kPa, the E_r had a negative value for both TSS (-7.7%) and Tu (-18.9%); additionally, fw became more cloudy with a greater amount of TSS and Tu. Consequently, the optical properties (Ref, and Trans) intensity ranges decreased to 16.28–75.16%, and 13.37–75.86%. In contrast, the Abs. intensity range increased from 0.096–0.267 at $hl_m \approx 20$ kPa with $E_r \approx 79.3$ and 82.4% for TSS and Tu in the first 10 h of the experiment, to 0.127–1.127% with -7.7 and -18.9% for TSS and Tu at the experiment end. Of these results, as the filtration process progresses, the values of E_r for both TSS and Tu decreased until the filter was clogged, and the values shifted to negative values (-7.7, -18.9%) for TSS and Tu at an $hl_m \approx 60$ kPa; this entails an increase in TSS, Tu and water cloudiness. It follows from the above that for both the Re, and Trans, the light decreased to 45.72, and 44.61% and there was an increase in the Abs light to 0.63% as a direct result of increasing the TSS concentration of 268.8 mg L⁻¹. Where TSS concentrations (composition and size) scatter light efficiently owing to their high refractive index relative to the water, they influence the scattering, absorption and transmission of light (Wozniak & Stramski 2004; Williamson & Crawford 2011; Al-Yaseri *et al.* 2013). Meanwhile, Tu causes cloudiness or a decrease in the transparency of water. The direction of the transmitted light path will undergo changes, being scattered when the light hits the particles (silt, clay, algae, organic matter and micro-organisms) in the water column (Sydor 1980; Ziegler 2002).

CONCLUSION

At different head losses the gravel filter reduced both TSS and Tu sharply at the beginning of the experiment; E_r for both had a negative relation with experiment accumulated time until the filter was clogged, and the values of E_r turned to negative values. In addition, the curves of optical properties for fw occurred in the range 350–400 nm. Furthermore, with the progress of the filtration process, and increase in head losses (from 20 to 60 kPa), both TSS and Tu in fw increased, leading to increase in the water suspended solids and pollutants, which is negatively reflected in the decrease in both Ref and Trans intensity, on the one hand, and the increase in the Abs intensity. So, the optical properties are considered a perfect indicator that can be relied upon in determining the necessity of filter backwashing.

DATA AVAILABILITY STATEMENT

All relevant data are included in the paper or its Supplementary Information.

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