Greywater Pretreatment Prototype Calibration with Integrated Filter

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***Abstract:** The sustainable management of greywater in decentralized systems is critical for regions facing water scarcity, particularly in isolated coastal communities. This study presents the calibration of a gravity-driven greywater pretreatment prototype equipped with a sargassum-based filter, designed to optimize water reuse while minimizing energy consumption. The system was retrofitted with high-resolution digital and mechanical manometers (Instrutek D600 and M-300) and Keller pressure cells to precisely measure local head losses. Laboratory experiments were coupled with numerical simulations in EPANET to calibrate the prototype, focusing on the hydraulic performance of the biodegradable filter. Results demonstrated an average pressure loss of 0.1234 bar (1.234 m.c.a.) across the filter, with the digital manometers proving superior for low-flow conditions (<0.5 L/s). The iterative calibration process, supported by EPANET's custom component module, enabled accurate estimation of the loss coefficient (K) for the sargassum filter, revealing its flow-dependent turbulence effects. This work advances the design of low-cost, eco-friendly treatment systems and underscores the synergy between experimental data and computational modeling for hydraulic optimization.*

***Keywords:** Head loss, pressure gauges, digital and analytical measurements, sargassum reuse*

1. Introduction

The global surge in sargassum blooms has transformed this once-ecologically beneficial seaweed into a pressing environmental and economic crisis, particularly in the Caribbean and Mexican coastal regions. Since 2011, unprecedented sargassum influxes have inundated shorelines, releasing greenhouse gases as they decompose, harming marine ecosystems, and costing millions in tourism and cleanup efforts. Traditional disposal methods—such as landfilling or offshore dumping—are unsustainable, exacerbating nutrient pollution and failing to address the root cause of blooms linked to climate change and agricultural runoff. However, sargassum's high porosity, organic composition, and metal-binding properties make it a promising candidate for repurposing in water treatment, offering a dual benefit: mitigating waste while addressing water scarcity.

In low-density coastal communities, where decentralized water systems are prevalent, greywater reuse presents an opportunity to reduce freshwater demand. Yet conventional treatment technologies often rely on energy-intensive processes or synthetic materials, which are economically and environmentally impractical for isolated households. Here, we propose an intelligent, nature-based solution: a gravity-fed pretreatment prototype that leverages sargassum as a biodegradable filter medium. By calibrating the system with high-resolution instrumentation and computational modelling, we aim to optimize hydraulic efficiency while transforming a waste product into a resource—a paradigm shift aligned with circular economy principles.

Previous studies have demonstrated sargassum's efficacy in adsorbing contaminants like heavy metals and dyes, but its hydraulic behaviour in flow systems remains poorly characterized. This gap is critical, as head loss directly impacts the feasibility of gravity-driven systems for household use. Earlier prototypes using aquarium pumps or low-precision manometers lacked scalability and accuracy. Our work advances the field by:

Repurposing sargassum as a low-cost, renewable filter material, reducing reliance on non-biodegradable alternatives.
Integrating digital sensors and EPANET modeling to dynamically calibrate head losses, ensuring energy efficiency.
Designing for real-world adaptability, with modular components suitable for coastal communities.
By addressing both the sargassum waste crisis and water scarcity, this research exemplifies how environmental challenges can inspire innovative, scalable engineering solutions.
The issue of scarcity and optimal use of potable water in areas with isolated homes necessitates the search for relatively simple technologies to be installed and used in such locations. Specifically, the volumes generated by graywater (from sinks, showers, and laundry) can undergo purification processes before potential reuse in a given household or prior to final disposal into the drainage system. Understanding the energy requirements of a filter-based treatment system helps conduct economic evaluation analyses to review the feasibility of implementing such systems. A fundamental problem is estimating the local head loss generated by the filter in the system once it is operational. In 2023 [1], a gravity-operated filter system prototype was implemented from an adaptation to a filter prototype that originally operated with an aquarium pump [2], and the local head loss coefficient curve (K) was estimated by testing different flow rates. At that time, the equipment used for pressure measurements had resolutions of 0.5 and 0.75 kgf/cm², and the system was subject to inherent errors attributed to the manual intervention required by the measurement team to control the experiment [3].
Among the studies conducted on the topic of local loss calculations, the work of Zitterell et al. (2014) [4] stands out. The authors developed a mathematical model to calculate these losses, using combinations of connectors and pipes characterized by their internal diameters and dimensions. They obtained head loss curves as a function of flow rate for different connectors. The model, based on Buckingham's theorem, relates head loss to diameters, conduit length, and flow velocity, and presented a determination coefficient of 93.31%, indicating excellent accuracy. The findings revealed that factors such as the internal diameter of the connector, pipe length, water flow velocity, Reynolds number, and Froude number significantly influence local head losses. This author also refers to studies by several authors [5-7], who experimentally obtained models of the local loss coefficient as a function of an obstruction index (degree of protrusion in the analysed section). In this research, it was proposed to re-equip the system with a sargassum-based filter to improve the accuracy of pressure measurement in the system before the flow enters the filter, as well as to calculate the local head loss coefficient K attributed to this special piece [8]. The equipment specifications are described in this document, along with the conceptual representation of the system in the open-source software EPANET [9], where the hydraulic simulation of the system was performed using numerical procedures.

2. Methodology

The following section outlines the experimental procedures and numerical modeling approaches considered in this study.

2.1 Steps to Follow for the Calibration of the Reequipped Prototype

1. Original system.
2. Acquisition of higher precision measurement equipment.
3. Installation of the new measurement equipment with different configurations of the filter system.
4. Initial functional tests of the equipment, without sargassum in the filter.
5. Calibration of instrument readings, in the laboratory and with numerical simulation using EPANET.
6. Pressure and flow measurements in the laboratory with the filter containing sargassum.
7. Calculation of local head loss and numerical simulation with EPANET.
8. Estimation of local head loss coefficient (K) curves.

2.2 Iterative Calibration in the Laboratory

If the piping system is operational, the equipment and loss coefficient can be calibrated through field tests by adjusting the theoretical values of local loss to match real-world measurements of pressure drop or flow rate [10].
For example:

1. Measure the pressure at two points: before and after the installation.
2. Estimate the fluid velocity based on the flow rate and the cross-sectional area of the pipe.
3. Adjust the theoretical value until the calculated pressure drop matches the measured drop.

2.3 Original Measurement Equipment

In the prototype, the pressure measurement equipment consisted of two dual-scale water pressure gauges (kgf/cm² + psi) with a maximum of 700 kgf/cm² (68,646,550 N/m^2). The resolutions were 0.5 and 0.25 kgf/cm² (that is 49,033.25 N/m^2 and 24,516.63 N/m^2, respectively) (Figure 1).

Fig. 1. Example of Pressure Measurement Equipment of the Original System. Source: [11]

2.4 Reequipped Prototype of the Filtration System

The digital manometers are from the brand Instrutek, model D600, and have a precision of 10 thousandths of (kgf)/(cm²). They also report units in PSI. The sampling frequency can be up to 5 seconds. The dial manometers are from the brand Instrutek, model M-300, and have a precision of 0.2 (kg_f)/(cm²). They also have a PSI scale, but their precision is lower, only going up to 0.5 PSI (Figure 2).

Fig. 2. Dial and Digital Manometers for the Reequipped System. Source: [11]

Additionally, digital pressure cells, Keller type, will be used, to have another point of comparison for pressure measurement.

2.5 EPANET Software

EPANET is an open-source software developed by the United States Environmental Protection Agency [3] (EPA, 2025), widely recognized for its capabilities in simulating hydraulic and water quality behavior in pressurized distribution networks. Its computational engine is based on the resolution of the fundamental equations of hydraulics—namely, the conservation of mass and energy—allowing for both steady-state and extended-period simulations of flow and pressure conditions. While EPANET is primarily applied in the context of potable water systems, its flexibility enables its adaptation to other hydraulic scenarios, including tertiary treatment systems operating under gravity flow. In such applications, the software can be used to model the hydraulic behavior of conduits and junctions, estimate head losses due to friction and local disturbances, and incorporate minor loss coefficients associated with special components such as sargassum-based filters. By accurately defining boundary conditions and elevation profiles, EPANET allows for the simulation of gravity-driven segments and supports the calibration of prototype systems. This facilitates the comparison between simulated and experimental data, enabling the estimation of the local head loss coefficient (K) and contributing to a more precise characterization of the system's hydraulic performance.

3. Results

The main findings of this study are highlighted below.

3.1 Schematic of the prototype

The sargassum-based water treatment system consists of an elevated tank, a flow meter type fluxometer for the flow descending from the tank, a valve, a pressure gauge, a filter filled with sargassum, another pressure gauge, and PVC piping along the conduit that finally connects to a hose whose water output is discharged into a cylindrical receiving tank. (Figure 3).

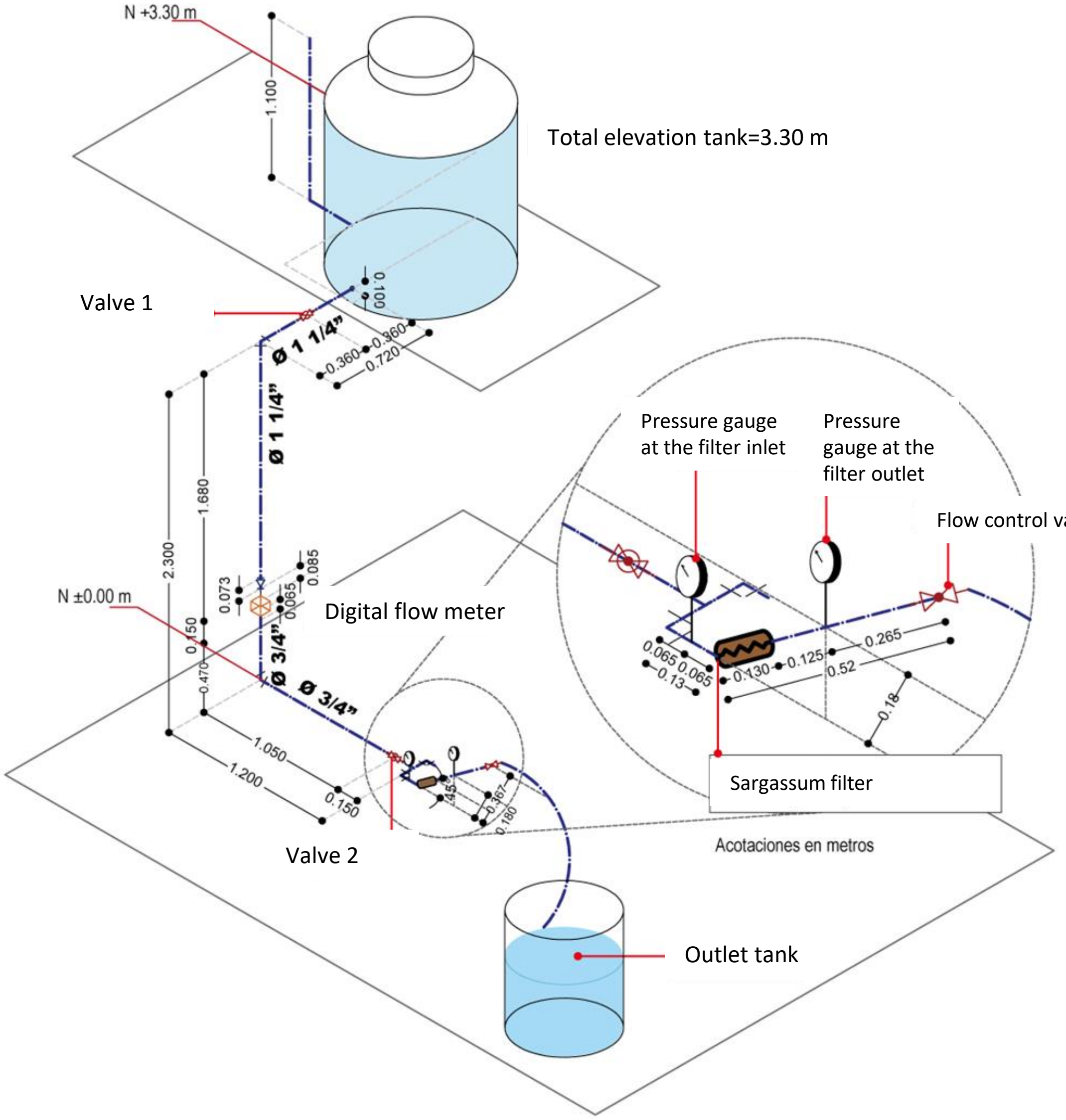

Fig. 3. Diagram of the Sargassum-Based Treatment System. Source: Adapted from [3]

Up to this stage of the investigation, regarding the digital manometers, differences in recorded pressures were found, attributed to a difference in head in the elevated tank; in previous Figure 2, there was a head of approximately 80 cm from the bottom of the tank, and in Figure 4 (indicated below), there was a head of about 110 cm.

Fig. 4. Digital Manometers (showing differences in their readings compared to Figure 2, attributed to head differences in the elevated tank). Source: [11]

3.2 Prototype Calibration Details

The prototype calibration was performed through an iterative process that combined laboratory experimental measurements with numerical simulations in EPANET. Key aspects are detailed below:

3.2.1 Physical Model Configuration

Infrastructure

1. 1,100-liter feed tank with a constant depth of 1.1 m.
2. PVC pipes with 2 valves, 2 elbows, a "T" connection, and a flow meter prior to the sargassum filter.
3. Two pressure cells (before and after the filter) to measure local pressure loss.
4. Measuring equipment:
5. Digital pressure gauges (Instrutek D600): Accuracy of 0.001 kgf/cm² (98.1 N/m^2), sampling rate of 5 seconds.
6. Mechanical pressure gauges (Instrutek M-300): Accuracy of 0.2 kgf/cm² (19.6 N/m^2).
7. Pressure cells (Keller): Range 0-10 bar, 4-20 mA output.

Initial tests without sargassum: Pressure losses in the system without the filter were measured to establish a baseline.

The data were compared with the EPANET model by adjusting friction coefficients and local losses in standard fittings (elbows, valves).

Inclusion of the sargassum filter

1. 10 g (0.01kg) of dry sargassum was placed on the filter and the measurements were repeated.
2. The average pressure loss recorded was 0.1234 bar (1.234 mca) between points 1 and 2 (before and after the filter).
3. Adjusting the K coefficient in EPANET:
4. The "Custom Components" module in EPANET was used to introduce the filter as a non-standard accessory.
5. The K value was calibrated iteratively until the simulated losses matched the experimental measurements (±2% error).

3.2.2 Calibration Results

K coefficient curve

A relationship between the flow rate (Q) and the local loss coefficient (K) was obtained for the sargassum filter, validating that K increases with the flow rate due to the greater turbulence generated by the biodegradable material.

Equipment comparison

Digital pressure gauges showed greater accuracy at low flow rates (<0.5 L/s), while mechanical gauges were more stable at high ranges.

4. Conclusions

High-precision instrumentation integration (e.g., digital manometers with 0.001 kgf/cm² resolution) significantly enhanced the reliability of head loss measurements, reducing uncertainty inherent in earlier prototypes. The calibrated K values for the sargassum filter validated its nonlinear relationship with flow rate, attributed to increased turbulence at higher velocities. This insight is critical for scaling the system for field applications, where flow variability is common. The hybrid approach—combining physical experiments with EPANET simulations—proved effective for calibrating non-standard components like the sargassum filter. By iteratively adjusting K in EPANET's custom module, the simulated and experimental pressure losses converged within ±2% error, demonstrating the model's utility for predictive design.
The success of the prototype underscores the promising potential of sargassum—an abundant and often underutilized marine biomass—as a sustainable filtration medium. This innovation not only offers an environmentally friendly solution but also contributes to the valorization of coastal waste. Nevertheless, several aspects warrant further investigation to enhance the system's performance and applicability.
Future research should focus on evaluating the long-term effects of clogging by experimenting with larger volumes of sargassum and extended operational periods. Additionally, improving energy efficiency is essential, particularly through the optimization of pipe networks to minimize head losses in gravity-fed systems. Finally, to ensure broader impact, efforts should be directed toward scaling the design for household or community-level implementation, especially in coastal regions where sargassum is readily available.
This research contributes to SDG 6 (Clean Water and Sanitation) by promoting low-energy greywater reuse. The methodology can be extended to other biodegradable materials, fostering circular economy strategies in water treatment.

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