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Deployment of Recyclable Polycarbonate as Alternative Coarse Media in Dual-media Rapid Filters

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Abstract

Sand and anthracite coal/granular activated carbon are commonly employed in traditional dual-media rapid filters to remove physical impurities present in influents. With increasing emphasis on sustainability, more water treatment facilities worldwide are opting for the use of eco-friendly materials which include recycled crushed glass, wood chips, and coconut shell based carbons. For instance, some filtration facilities of private pools in the United States have adopted recycled glass and obtained high quality effluent. The deployment of eco-friendly filter media in rapid filters deserves attention. In this study, sewed polyester bags which contained recyclable polycarbonate pellets (RPCs) were deployed as an alternative coarse media in a lab-scale dual-media rapid pressure filter setup. By coupling RPCs with sand, the following performance criteria were attained during the experimental runs when compared with the traditional dual-media: (a) similar rate of head loss development while maintaining acceptable effluent quality, and (b) improved clogging distribution within the filter. Life-cycle analysis (LCA) was also carried out with the Gabi Education software to assess the environmental footprint associated with various dual-media combinations. It is hopeful that the obtained LCA results would provide useful insights to industrial decision-makers who wish to improve the company's environmental performance index.

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Keywords: dual-media rapid filters, eco-friendly filter media, life-cycle analysis

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1. Introduction

Dual-media rapid filter technology is extensively employed as the pre-treatment step in many medium- and large-scale desalination plants worldwide. Some examples are the 250,000m^3/day Sydney Water plant in Australia, the

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200,000m^3/day Hamma plant in Algeria, and the 320,000m^3/day Ashkelon plant in Israel [1]. In dual-media rapid filters, fine sand and coarse anthracite coal/granular activated carbon (GAC) are commonly used as the dual-media combination for treating influents by physically removing its impurities [2]. However, the extraction of sand and anthracite coal in bulk quantities can lead to adverse effects to the environment. For example, the mining of anthracite coal results in acid mine drainage, land disturbance, upset of biodiversity and emissions of air pollutants from operational machineries [3]. Similar detrimental effects have also been reported for sand excavation [4]. Thus, reducing the reliance on these filter materials would improve the environmental performance of pre-treatment facilities. The use of recyclable materials is one possible avenue to achieve the objective.

With increasing emphasis on sustainability, the development of eco-friendly filter media is gaining popularity. Aksogan et al. (2003) demonstrated that higher turbidity removal efficiencies were achieved using crushed apricot shells combined with sand, when compared to the traditional dual-media. Additionally, the crushed apricot shells minimized the degree of intermixing with the sand layer during filter backwashing. The analysis was, however, incomplete with no mentioning of the head loss development rate [5]. Till date, there have been limited studies on the deployment of recycled materials in rapid granular filtration. Xie (2005) filed a patent on the use of rubber scrap from recycled tires as an alternative filter material. The novel media performed similarly to the conventional dual-media in terms of its turbidity removal efficiencies, even under high hydraulic loading rates. Furthermore, the compressible nature of the media resulted in a slower rate of head loss development and greater depth filtration [6]. Soyer et al. (2013) demonstrated that crushed recycled glass is a viable alternative for treating raw waters with low turbidity (6NTU to 14NTU). Higher quality filtrate and lower head loss were attained using crushed glass and anthracite coal combination. However, their study did not evaluate the replacement of anthracite coal with crushed recycled glass [7].

This study aims to evaluate the suitability of recycled polycarbonate pellets (RPC) as an alternative coarse media to the traditional anthracite in a typical dual-media rapid filter. The engineering novelty involved was the coupling of the RPC with sand (PC configuration), which did not fulfil the recommended uniformity coefficient and effective sizes deployed in traditional dual-media rapid filters. The assessment of the alternative dual-media was compared to the traditional dual-media based on the following criteria: (a) effluent point turbidity and (b) rate of head loss development. A series of experiments were carried out in attempts to achieve the study's objective. Additionally, the environmental burdens associated with the proposed configuration was analysed using a life cycle analysis (LCA) tool, and subsequently also compared against that of the conventional dual-media (DM configuration).

Nomenclature

d_{10}	10^{th} percentile of grain diameter, i.e. effective size
d_{50}	Median grain diameter
SG	Specific gravity
UC	Uniformity coefficient

2. Methodology

2.1. Rapid filtration experiments

Rapid filtration experiments were conducted in a lab-scale pressurized down-flow column, as schematically represented in Figure 1. The physical properties of the deployed dual-media (combination of sand and anthracite, sand and RPCs) are summarized in Table 1. It is worth noting that the physical shape of RPCs appeared to be highly homogeneous with an elliptic cylindrical shape having average dimensions of 3.0mm height, 3.0mm and 2.0mm ellipse axis. During the preparatory stage, the RPCs were packed into sachets made of polyester mesh with average dimensions of 75mm ×75mm× x15mm.

Before the start of each experimental run, 440L of tap water was added into the influent tank and mixed thoroughly with a specific mass of 20μm or 50μm particulate matter, Polyamide Seeding Particles, to emulate monodisperse influent with a specified concentration. The influent solution was subsequently pumped into the filter column through the filter inlet at a pre-determined flowrate without undergoing any pre-treatment step.

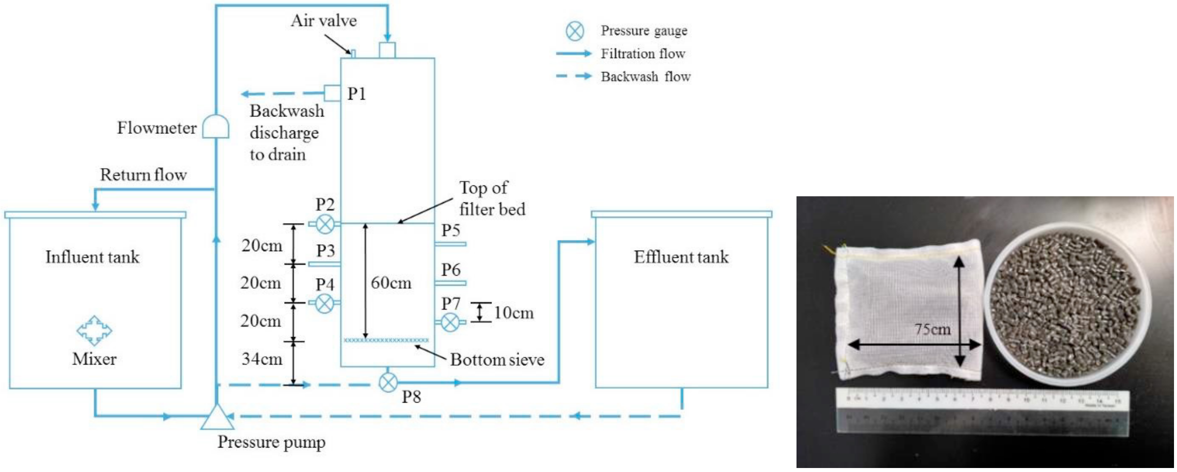


Fig 1. (Left) Schematic representation of lab-scale rapid pressure filter setup; (Right) A typical representation of the packed RPCs.

Pressure gauge readings at sampling ports P2, P4, P7 and P8 were recorded at 5 seconds after the start of the experiment to represent the clean bed pressure head values. At every 1-minute interval, pressure readings of the same sampling ports were recorded for computing the transient clogging head loss incurred. 150ml samples were extracted from the designated sampling ports and effluent discharge point at every 6-minute interval to test for turbidity. Hach 2100N Laboratory Turbidimeter was used to measure the turbidity value of samples in Nephelometric Turbidity Units (NTUs). The return flow valve was consistently adjusted throughout the experimental run to ensure constant-rate filtration mode.

Table 1. Filter media configurations and physical properties of filter media.

Filter media configurations	**Filter layer and medium**	**Layer depth (cm)**	**SG**	**d_{50} (mm)**	**d_{10} (mm)**	**UC**
Sand and anthracite (DM)	Bottom: sand	30	2.67	0.54-0.60	0.43	1.3
	Top: anthracite	30	1.40	2.00	1.38	1.6
Sand and recycled polycarbonate (PC)	Bottom: sand	40	2.67	0.54-0.60	0.43	1.3
	Top: RPC (packed in sachets)	20	1.20	-	-	-

The duration of the rapid filtration run was fixed at 42 minutes for all experiments. The filtration operation was terminated prematurely upon achieving any of the following conditions (a) turbidity breakthrough when removal rate at effluent discharge point dropped below 90% or (b) total clogging head loss incurred exceeded the allowable value of 2m. Backwashing of the dual-media filter was initiated at the end of each experimental run.

The clogging head loss, $H_{clogged}$ measurements for P4, P7 and P8 were normalized with the initial clean bed head loss, H_{clean} which was represented by H^N. A proposed homogeneity index, I was computed by Equation 1 to represent the degree of homogeneity of the clogging behavior within the filter.

$$I = \frac{m_{40/50}}{m_{94}} \tag{1}$$

where I is the homogeneity index, $m_{40/50}$ is the rate of transient variation of hydraulic gradient at 40cm depth or 50cm depth, and m_{94} is the rate of transient variation of hydraulic gradient hydraulic gradient at 94cm depth.

2.2. LCA studies

GaBi Education software was utilized to compare the environmental impacts of employing the two filter media configurations: DM and PC, in the pre-treatment process of water desalination. To allow comparisons at an industrial level, a theoretical model was established to emulate the real-life conditions. The model was a single stage dual granular media pressure filtration system designed for a virtual 40,000m^3/day desalination plant, which was arbitrarily located in Tuas, Singapore. Important design and operational criteria involved in the rapid filtration system were taken from reference [2]. The functional unit was defined as 40,000 m^3/day water produced. In general, the life cycle of filter media consists of four stages, which includes extraction, manufacturing, useful life during filtration, and disposal. The system boundary of DM and PC configurations is illustrated in Figure 2. Six scenarios were formulated for comparison purpose, combining different types of filter media with various end-of-life disposal methods:

- Scenario A Landfill disposal of sand and anthracite being incinerated
- Scenario B Recycling of sand and landfill disposal of anthracite
- Scenario C Recycling of sand and anthracite being incinerated
- Scenario D Landfill disposal of sand and recycling of RPCs
- Scenario E Recycling of sand and landfill disposal of RPCs
- Scenario F Recycling of sand and recycling of RPCs

The life cycle impact assessment was carried out using the CML method available in GaBi Education, which is a problem-oriented (mid-point) approach that focuses on emissions to the environment. The environmental impact categories results include: Global Warming Potential in 100 years, Abiotic Depletion (fossil), Acidification Potential, and Human Toxicity Potential.

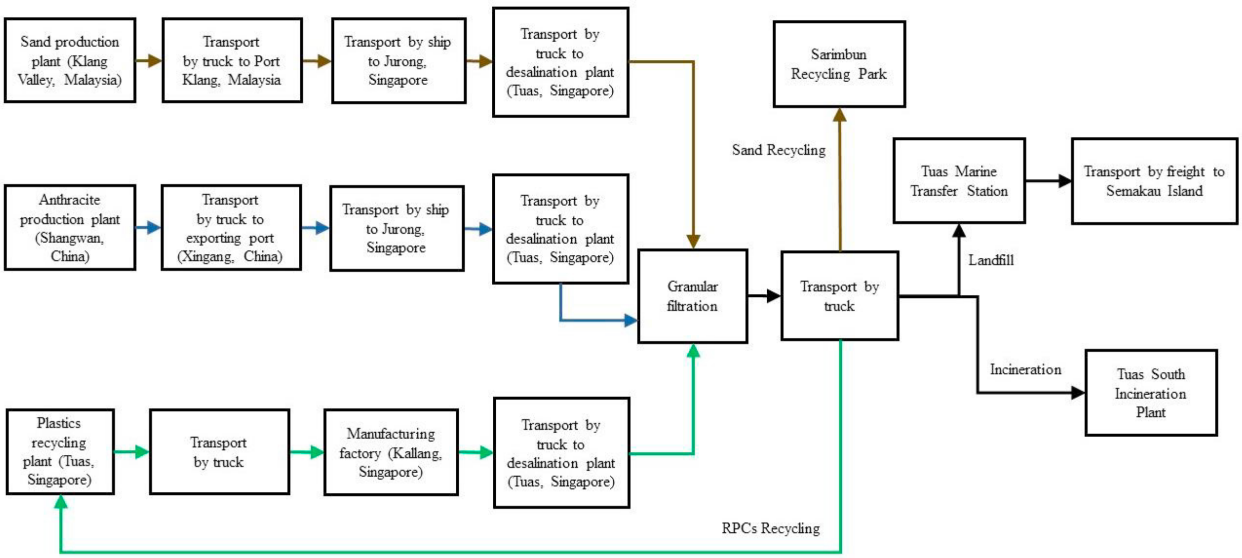


Fig 2. System boundary for DM and PC configurations and Processes involved in the LCA study.

3. Results and Discussions

3.1. Experimental results

The changes of effluent turbidity with time are presented in Figure 3. The PC configuration was able to remove more than 91% solids when used for the filtering of 20μm monodisperse suspensions under varying turbidity levels and flow rates. In comparison, the DM configuration trapped slightly more particles, with solid removal efficiencies greater than 95%. When used for the filtering of 50μm particles under varying turbidity levels and flow rates, both configurations exhibited high removal efficiencies, where approximately 99% of solids were removed.

For the rapid filtering of 20μm suspensions under varied loading rates, the head loss augmented at a lower rate in PC than in DM across different media sections in most cases, as demonstrated by its lower *m* values summarized in Table 2. Additionally, the homogeneity indices of PC configuration were relatively closer to the baseline value 1.0, indicating that the solid trapping mechanism was distributed more evenly along the PC filter bed, as compared to DM.

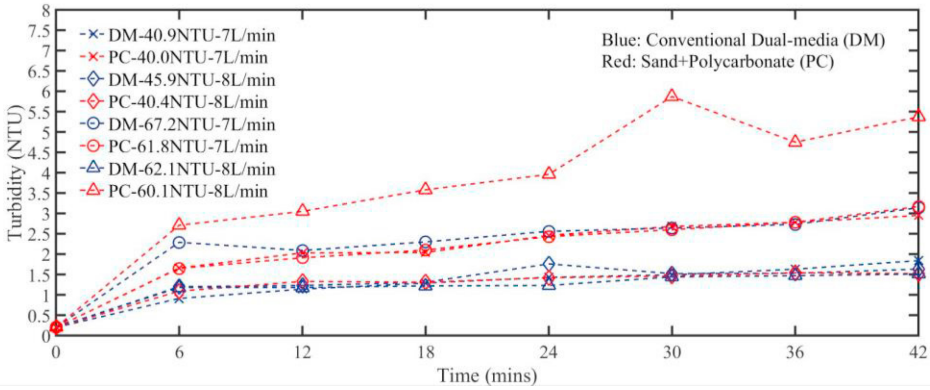


Fig 3. Turbidity at P8 (effluent) for rapid filtering of 20μm monodisperse suspensions.

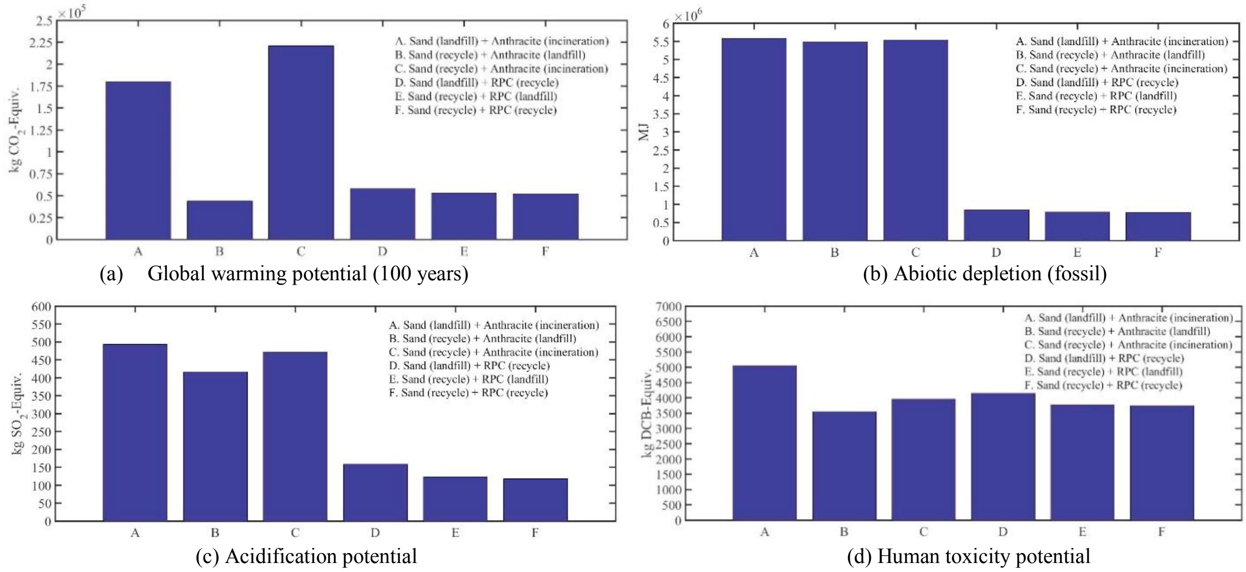
Table 2. Summary of *m* and *I* values across depths, for rapid filtering of 20μm monodisperse suspensions.

Experiment	m_{40}	I_{40}	m_{50}	I_{50}	m_{94}	I_{94}
DM-40.9NTU-7L/min	0.0043	1.79	0.0033	1.38	0.0024	1.00
PC-40.0NTU-7L/min	0.0023	0.92	0.0029	1.16	0.0025	1.00
DM-45.9NTU-8L/min	0.0035	1.84	0.0030	1.58	0.0019	1.00
PC-40.4NTU-8L/min	0.0015	0.83	0.0017	0.94	0.0018	1.00
DM-67.2NTU-7L/min	0.0031	3.10	0.0026	2.60	0.0010	1.00
PC-61.8NTU-7L/min	0.0034	1.89	0.0030	1.67	0.0018	1.00
DM-62.1NTU-8L/min	0.0054	1.54	0.0055	1.57	0.0035	1.00
PC-60.1NTU-8L/min	0.0024	1.50	0.0022	1.38	0.0016	1.00

3.2. LCA impact assessment

Based on the theoretical desalination model, the PC configuration required 431,472kg sand and 52,608kg RPCs, while 322,536kg sand and 141,120kg anthracite constituted the DM configuration. The amount of greenhouse gasses emitted in equivalence of carbon dioxide through adopting PC is significantly lower than DM in Scenarios A and C, as displayed in Figure 4(a). The high carbon footprint in both Scenarios A and C is primarily due to the large amount of greenhouse gasses generated from anthracite incineration. The depletion of non-renewable resources using PC and DM is exemplified in Figure 4(b), which clearly shows that PC is a more environmentally preferable choice, consuming about 84.6% less fossil throughout its lifecycle.

In summary, the deployment of PC configuration for the pre-treatment step of water desalination yielded the following benefits: (a) generated low greenhouse gasses emissions, (b) consumed less non-renewable fossil, and (c) caused less toxicity to the environment. Among all the studied scenarios, the PC configuration adopting recycling during end-of-life (Scenario F) delivered the best environmental performance.



(a) Global warming potential (100 years)

(b) Abiotic depletion (fossil)

(c) Acidification potential

(d) Human toxicity potential

Fig 4. LCA impact categories (CML 2001)

4. Conclusion

This study evaluated the suitability of recycled polycarbonate pellets (RPC) as an alternative coarse media to the traditional anthracite in a dual-media rapid filter. The experimental results showed that the PC configuration is capable of removing more than 90% of influent turbidity, alleviating head loss development rate, and improving homogeneity of solid removal along the filter bed. The LCA results also concluded that the overall environmental performance for the pre-treatment stage of water desalination could be further improved with the deployment of the PC configuration and adoption of recycling during end-of-life of the media.

This research can be refined and extended for future studies from the following aspects: (a) additional experiments on the PC configuration to identify the optimal proportion of filter media layers, (b) modifications to the polyester bags such that the backwash effectiveness can be further improved, and finally (c) LCA studies to account for the effect of varied filter media lifespan on environmental degradation.

Acknowledgements

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