# CRUSHED GLASS AS A FILTER MEDIUM FOR ON-SITE WASTEWATER TREATMENT

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## ABSTRACT (500 WORDS MAXIMUM)

The on-site wastewater treatment system (OWTS) with a sand trench is an economical option for residents in rural areas or the countryside where a centralised sewer system is inaccessible. 2A sand achieves improved filtration, microbial activity and consistent long term performance when compared to gravel or scoria based trench systems. However, it is expensive and only readily available in a few areas across New Zealand. Additionally, it has a reputation for premature blockage when overloaded or compacted. The aim of this project is to investigate and critically evaluate the performance of Crushed Glass (CG) with respect to 2A sand when treating primary treated effluent from a septic tank. A test rig was designed and constructed to simulate the real environment of the sand column in a discharge control trench. The treatment efficiency of three filters was recorded and compared in this study. Overall, the CG loaded at 25mm/day (CG25) and 50mm/day (CG50) provided an average of 13% and 6% more Total Nitrogen (TN) reduction than the sand filter respectively. The CG50 filter performed similarly at 50mm/day as the 2A sand filter in terms of Total Suspended Solids (TSS) and Biochemical Oxygen Demand ($BOD_5$) removal, the CG25 exhibited low TSS and $BOD_5$ removal rates at the start of the trial (likely due to residual liquid contamination from the bottles when crushed), improving over the sampling period and ultimately achieving similar results to the filters loaded at 50mm/day. Lifecycle cost analyses and carbon balances were completed for the two media. It highlighted that the current price of CG is only half of 2A sand, yet it produces significantly less $CO_2$ emissions than 2A sand. A 3-bedroom dwelling could save up to $500 and reduce 200kg of $CO_2$ released to the environment annually when 2A sand is substituted for CG. Based on the findings of this paper, it is likely that the reduced installation cost, lessened environmental impact and theoretical availability will lead to CG systems becoming more common in New Zealand and abroad.

## KEYWORDS

### Crushed glass, Carbon emission, Septic discharge, Dinitrification

## PRESENTER PROFILE

Marc is a specialist on-site wastewater treatment engineer. With 10 years of engineering experience devoted to sustainable engineering, bridging the gap between practical system design through to legislative framework implementation. Marc is a shareholder of TM Consultants Limited and is the team leader for the External Infrastructure and Planning department.

# INTRODUCTION

It is estimated that around 270,000 homes in New Zealand rely on onsite wastewater treatment systems (OWTS) to manage their wastewater, with 76 per cent of settlements in Southland using the septic tank as their wastewater disposal system [1]. A conventional septic system works adequately in well-draining soil; however, it does not provide an adequate level of wastewater treatment in areas with sensitive environments, poorly draining soil, or shallow groundwater. The OWTS with a sand trench is an economical option for rural or countryside residents where a centralised sewer system is unavailable [2].

Sand sorted to match the 2A distribution curve achieves a hydraulic conductivity over 500cm/day, leading to a high hydraulic capacity and consistent effluent filtration performance. In the absence of macropores, parasites are removed by filtration in this sand. Luana et al. conducted a study on the performance of a full-scale sand filter treating septic tank discharge [3]. 2A sand has been used as a filter medium for a long time and has a good track record. The sand can remove up to 98% of Biochemical Oxygen Demand ($BOD_5$), 94% of Total Suspended Solids (TSS), 27% of Total Nitrogen (TN) and a log 3 of Faecal Coliform (FC) in the septic tank effluent from a single home. Over the seven-month investigation, the system achieved TSS removal of 87.8%, $BOD_5$ removal of 92.7%, TN removal of 32%, and log 4 of E. coli reduction. [4].

In New Zealand, an intermittent single-pass sand filter is promoted as an option for secondary treatment of domestic wastewater. Effluent from a sand filter could be classified as high quality with typical TSS and $BOD_5$ concentration of less than 5 mg/L, phosphate of less than 10 mg/L and ammonia of less than 5 mg/L [5]. At present, almost all recycled glass in New Zealand end up in landfills; 60,000 tons in 2016, with a fraction being used as aggregates, sandblasting media, or landscaping materials, meanwhile, the specialist sand required for sand filter construction has to be quarried from selected rivers dispersed across the country [6].

Recycled glass has also been used as a filter medium in several trials for secondary treatment of wastewater. Secondary and tertiary treatment of sewage using CG have been studied in the US and the UK with periodic backwashes for application in wastewater treatment plants [7]. A pilot-scale and a field scale application of recycled glass have been studied for wetland wastewater treatment [7] [8]. Laboratory-scaled filter column has been used to compare the treatment performance of CG versus sand and soil [9]. From these trials it has been found that CG performed equally well as sand, especially in TSS, $BOD_5$, TN and FC removal. Published research supported by Clean Washington Center investigated the use of CG as a filter medium for intermittent sand filter treating a septic tank discharge from an individual home [10]. The trial was set up and monitored over two years to measure the filtration performance of CG and C-33 sand (ASTM C-33 guideline values are similar to the 2A rating of the MESO diagram) under the same loading condition. It was concluded that CG could be used as an alternative to C-33/2A sand for the filter system. While C-33 sand out-performed CG by a slight margin in terms of $BOD_5$, TSS, O&G, and FC reductions, CG performed slightly better than C-33 sand in terms of nitrate reduction [10].

Dryden Aqua found that glass media dealt very well with wastewater with a high concentration of nutrients and bacteria and removed 90% to 95% of solids and chemicals in wastewater [11]. Horan and Lowe also found that medium-size glass and sand had similar TSS removal rates [12]. For solids concentration less than 70 mg/L, glass achieved up to 75% of TSS removal. Hu and Gagnon conducted a pilot-scale studying the effect of hydraulic loading rates, dosing frequency, recycled ratio and media characteristics on the performance of recirculating biofilters treating domestic wastewater [13]. Different media such as sand, glass, textile and peat were compared and found that glass performed equivalent to the sand media. The study also found that higher dosing frequency at low recirculation ratios improved $BOD_5$ removal significantly.

Gill et al., from Ireland conducted a trial that compared the treatment efficiency of sand and glass as filter media for polishing filters treating on-site wastewater from a single house over two years [14]. The results showed that on average the glass filter performed equivalent to the sand filter for the majority of monitored parameters ($BOD_5$, COD and FC). However, the glass filter performed much better than the sand filter in terms of total nitrogen reduction, at 1.5 times. In contrast, phosphorous removal was higher in the sand filter than the glass filter, at 51% and 40% reduction.

Additionally, the use of CG in filtration experiments was also highlighted in a few studies. Piccirillo examined the use of pulverised waste recycled glass as filter media for slow sand filters [15]. The glass was pulverised using a fail mill pulveriser and the product met the requirements of ASTM C-33 (comparable to 2A sand). The trial was operated for eight months and at the end of the period, the sand filter with glass media performed just as well as the sand filter with silica sand, achieving 56% to 96% of turbidity removal; a log 4 to complete coliform removal; a log 5 of giardia cysts removal and a log 4 of cryptosporidium cysts removal.

There was little-to-no information about the long-term performance of CG as filter media for OWTS. However, it was shown in previous research that CG media could potentially achieve a 91% reduction in TSS, 96% reduction in $BOD_5$, 29% reduction in TN, and a log-3 of FC when used for small-sized wastewater treatment units [10].

Besides the evaluation of performance between CG and 2A sand as filtration media in the New Zealand context. This research also compares the effect of different hydraulic loadings on the performance of CG filters, which has not been investigated in any published studies. Additionally, case studies have also been conducted to compare the cost and the $CO_2$ emissions of the two media, which provides valuable information for any future studies into CG.

# METHODOLOGY

## THE TEST RIG

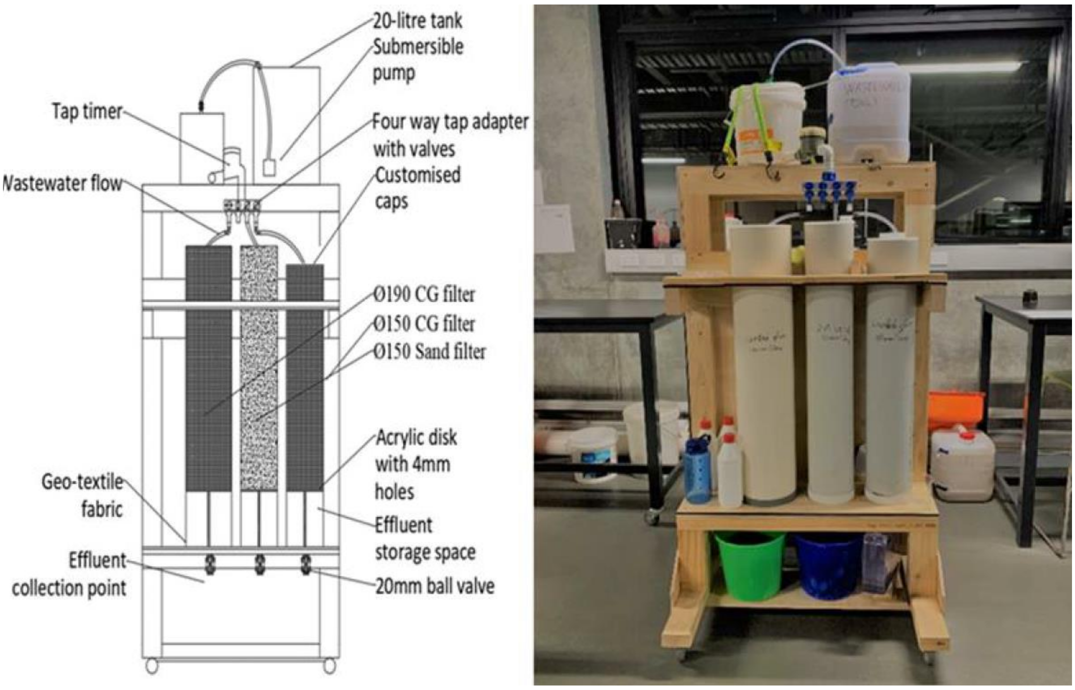


*Figure 1: The schematic and built test rig*

The test rig simulated a discharge control sand trench through a sand column treating septic tank discharge from a single house in Wainui, Akaroa. The septic tank discharge (filter influent) was collected on a weekly basis and stored on the 20-litre container as shown in Figure 1. The effluent was pumped to a smaller container by a program-controlled submersible pump from the main tank and was distributed to one 2A sand filter and two CG filters through a series of valves and tubes.

The 2A sand filter in the middle pipe and the CG filter on the right-hand side was designed with a hydraulic loading of 50 L/m$^2$/day (equivalent to 50 mm/day) and the CG filter on the left-hand side was designed with a hydraulic loading of 25 L/m$^2$/day. The filters consist of a layer of fabric mesh to protect the surface of the filter from hydraulic erosion, an effective media depth of 600mm and a layer of Bidim 19 geotextile to stop the media from slipping through the base of the filters. Sampling buckets were placed directly under the filters to collect effluent for analysis.

Figure 2. displays the visual similarity between the sand media used in this study. Figure 3 showed that the material had a uniformity coefficient (Uc=D60/D10) of 3.79 and a mean grain size of 0.35 mm. Therefore, when plotted on the MESO diagram, the sand fell into the lower end of the 2A range.

*Figure 2: 2A sand (left) crushed glass (right)*

The glass media used in this study was CG, obtained from Fulton Hogan Quarries Canterbury. Figure 3 showed that the material had a uniformity coefficient (Uc=D60/D10) of 6.91 and a mean grain size of 2.20 mm. Therefore, when plotted on the MESO diagram, the sand fell into the higher end of the 2A range. Both samples however were both met the 2A grading.

**2A sand**

| SIEVE SIZE (mm) | % PASSING SIEVE | Diameter Measurements (Linear interpolation) |
|---|---|---|
| 9.5 | 100 | |
| 4.75 | 100 | Sorting CU = 3.79 |
| 2.36 | 79 | |
| 1.18 | 70 | |
| 0.600 | 63 | |
| 0.300 | 46 | d50 = 0.35mm |
| 0.150 | 11 | |
| 0.075 | 1 | |

**CG (2A)**

| SIEVE SIZE (mm) | % PASSING SIEVE | Diameter Measurements (Linear interpolation) |
|---|---|---|
| 13.2 | 100 | |
| 9.5 | 100 | |
| 6.7 | 97 | |
| 4.75 | 89 | Sorting CU = 6.91 |
| 2.36 | 55 | |
| 1.18 | 30 | D50 = 2.20mm |
| 0.600 | 16 | |
| 0.300 | 8 | |
| 0.150 | 4 | |
| 0.075 | 1 | |

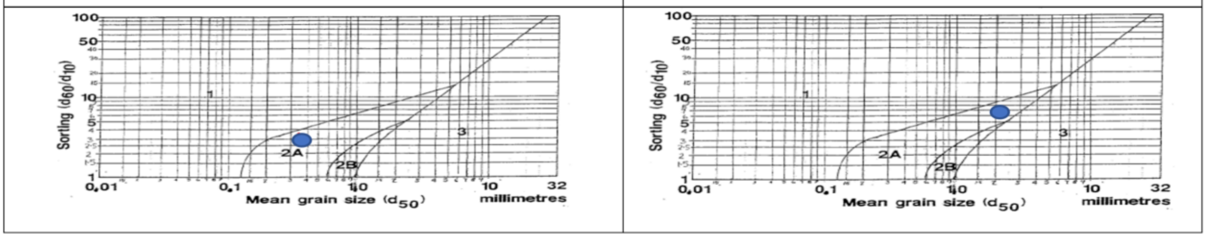


*Figure 3: Filter sand sieve analysis (Source: Adapted from Fulton Hogan)*

## SAMPLING AND ANALYSIS

The overall performance of filter media has been compared in six different wastewater parameters (TSS, $BOD_5$, TN, E.coli, pH and Temp). Sampling was carried out weekly throughout the study; each sampling volume was calculated based on the hydraulic loading rate of three filters and the sampling frequency. All filter influent and effluent samples were analysed for wastewater parameters at the same time.

## HYDRAULIC LOADS

The hydraulic loads for the 2A sand filter and the CG50 filter were 50 mm/$m^2$/d and the hydraulic load for the CG25 filter was 25 mm/$m^2$/d. The filters were dosed three times per day throughout the trial with a rest period of eight hours between pumping cycles.

The test rig was located in an airconditioned laboratory at ARA at the Madras Street Campus. The average temperature across the trial was 19°C, with a low of 17°C and a high of 22°C. The influent pH level ranged from 6 to 9 across the trial. Likely influenced by the COVID-19 lockdown and increased occupancies over three weeks during testing.

It was noted that the family using the wastewater system providing effluent samples were advised to not change their existing cleaning regime, chemicals and to continue using the system as per their normal habit.

# RESULTS AND DISCUSSIONS

## SEPTIC TANK DISCHARGE (INFLUENT)

The waste strength data for septic tank discharge (influent) are shown in Table 1. The average waste concentration of septic tank discharge throughout the study was 56.1 mg/L for TSS, 107 mg/L for $BOD_5$, 43.8 mg/L for TN, 7.4 for pH and 19.8 °C for temperature.

When comparing septic tank effluent with the typical waste strength values for primary treated wastewater as indicated in Table 1, the result was well within the expected range.

*Table 1: Typical domestic effluent quality before and after sand filter*

| Treatment system | Typical concentration | | | |
|---|---|---|---|---|
| | g/$m^3$ | | | cfu/100 mL |
| | TSS | $BOD_5$ | TN | FC |
| Septic tank with effluent filter [23] | 20-50 | 100-140 | 50-90 | $10^5$-$10^{10}$ |
| **Septic tank discharge (this trial)** | **56.1** | **107** | **43.8** | **NI** |
| Septic tank with single-pass sand filter [23] | 0-5 | 0-5 | <30 | 4 x $10^2$ – $10^4$ |
| **Septic tank with 2A sand filter (this trial)** | **3.6** | **5.5** | **15.2** | **NI** |

## EFFLUENT QUALITY MONITORING

The removal of TSS and $BOD_5$ in wastewater is accomplished by both physical and biological mechanisms. The filter media acts as a strainer to retain solids from wastewater in the gaps between the media particles and the naturally occurring microbes inside the filter will consume contaminants in the wastewater to grow and eventually form a microbial biomat. A healthy biomat is capable of removing bacteria and viruses. A working filter with abundant oxygen and food supply (contaminants in wastewater) should exhibit a consistent reduction of TSS and $BOD_5$ once established (after week 5).

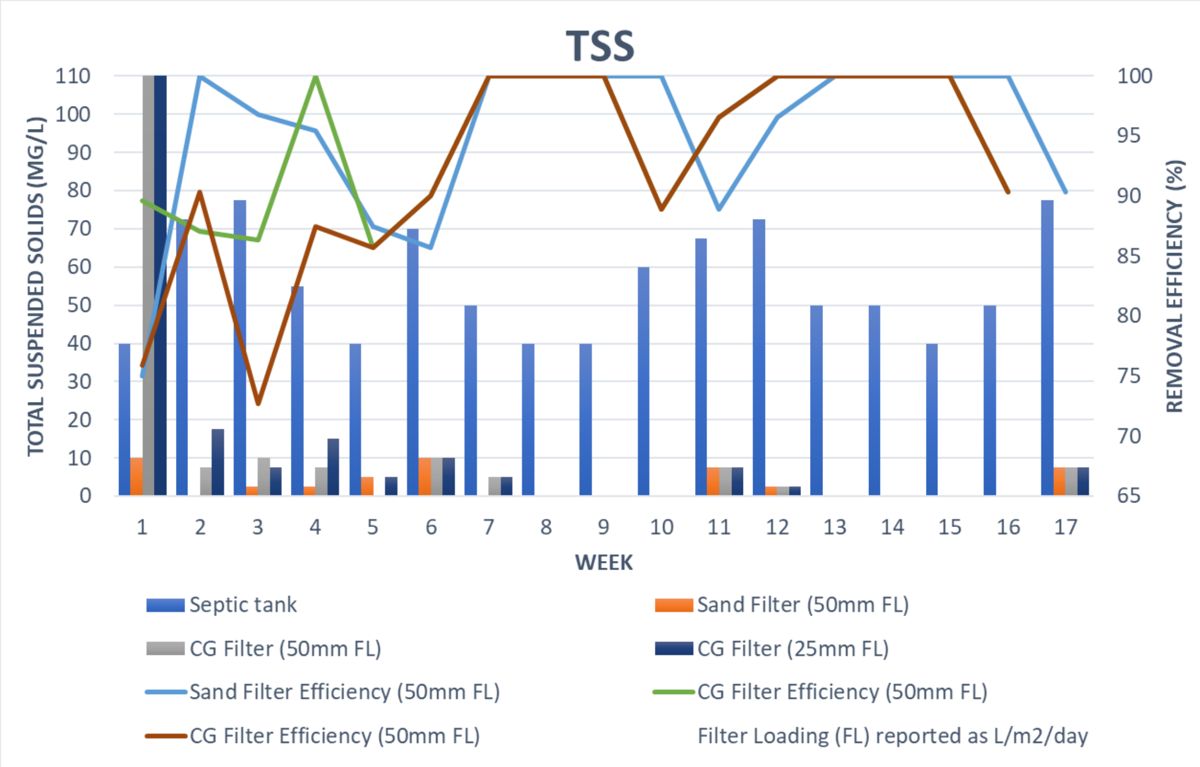


*Figure 4: TSS results of filter influent and effluent over seventeen weeks*

The concentration and removal efficiency of filter influent and effluent were recorded over seventeen weeks, as shown in Figure 4.

CG as a filter material does not go through a washing and drying process during production like 2A sand, therefore resulting in the excessively high concentration of TSS and $BOD_5$ during the first week(s) of the trial. Glass sourced from wine or milk bottles can have residues that can impact the quality of the filtrate from the base of the crushed glass columns. In areas where the receiving environment may be adversely affected by the initial flushing or washing of the glass media, clean glass from windscreens or windows may be more suitable.

There were a few special occasions that resulted in the abnormally high concentration of TSS and $BOD_5$. Week 11 to week 13 of the trial fell into the lockdown period in Christchurch and Week 17 fell into the long weekend of Labour Day.

Leaving aside those mentioned occasions, the sand filter showed a good and consistent performance in TSS reduction over the first six weeks and eventually achieved <1 mg/L of TSS over most of the period. The $CG_{50}$ filter showed a slightly fluctuating trend over the first seven-week period then achieved a 100% removal rate for most of the weeks after. The $CG_{25}$ filter showed the lowest removal rate in the three over the first seven-week period. In general, each filter seemed to have a different removal efficiency at the start, but all achieved their maximum removal rates after week eight which were very similar.

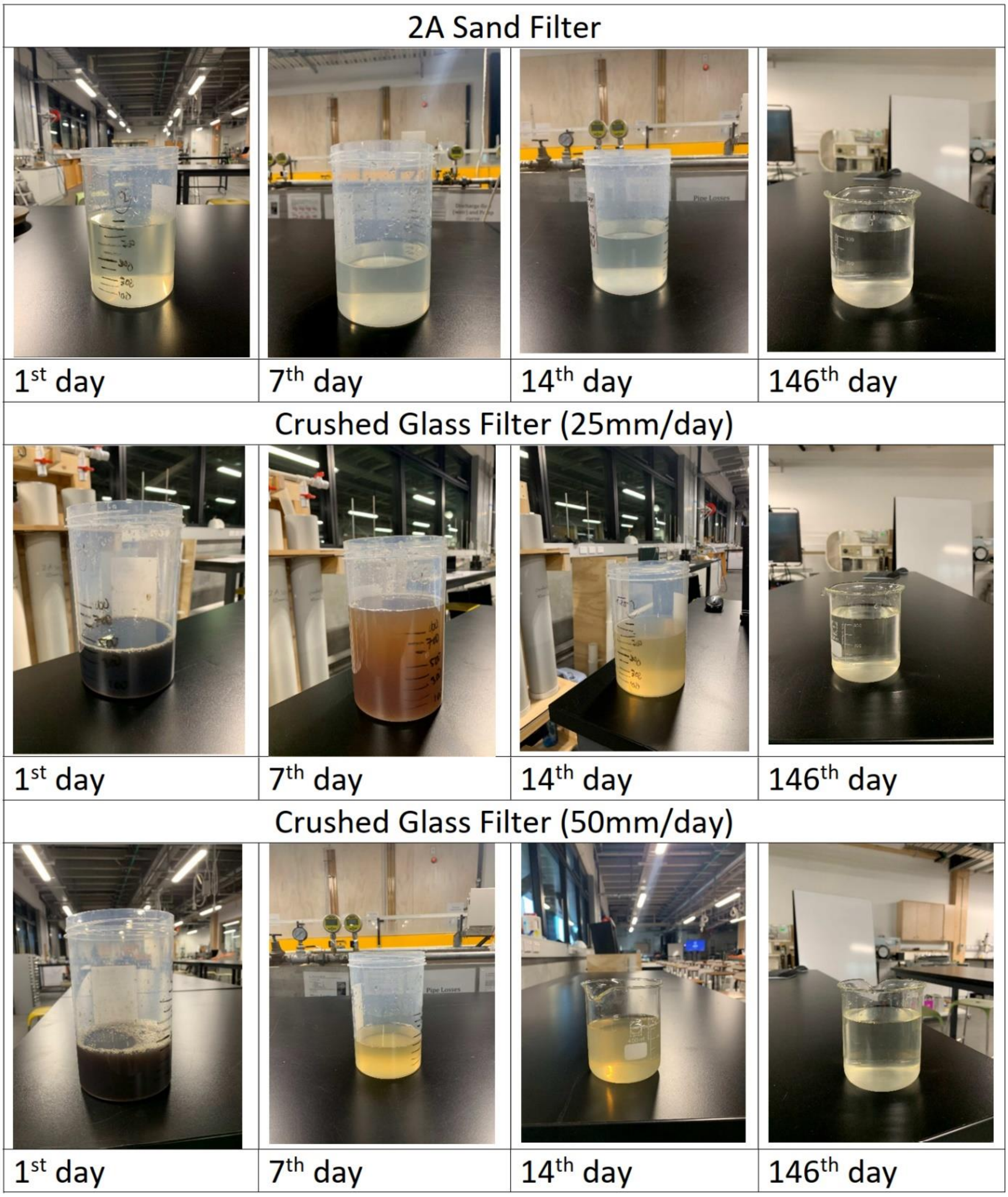


*Figure 5: Turbidity reduction throughout test period*

Figure 5 contains images of the filtrate from the base of the sand columns throughout the testing period. The effluent samples obtained on the first day of testing provided a clear visual representation of the residual contaminants that remain in the crushed glass media. As the media is washed, the filtrate becomes progressively cleaner and the three samples become visually indistinguishable by the end of the 17th week of testing, with the lower loading rate sample taking the longest to clear.

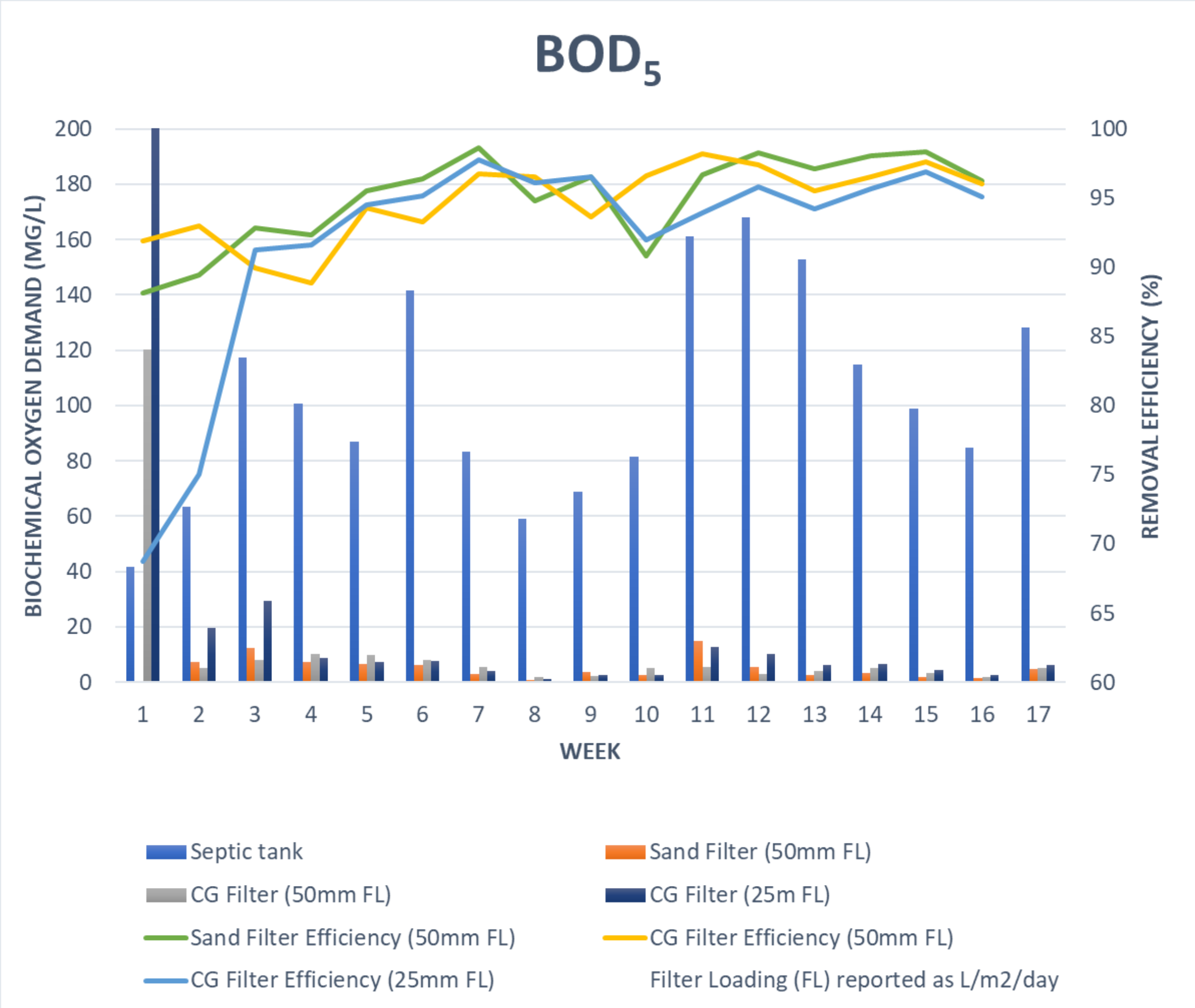


*Figure 6: $BOD_5$ results of filter influent and effluent over seventeen weeks*

Figure 6 shows the concentration and removal rates of $BOD_5$ in septic tank discharge and three filter effluents. The reason for the high concentration of $BOD_5$ during the $1^{st}$, $11^{th}$ to $13^{th}$ and $17^{th}$ week is as mentioned in the previous section.

From week three to week 7 and week 12 to week 15, the sand filter achieved a 95.9% removal which coincided with the times when the filter achieved a 100% removal rate TSS. The $CG_{50}$ filter showed a slightly fluctuating curve at the start of the trial, from week one to week five, but gained a steady increase in the $BOD_5$ removal rate afterwards, averaging nearly 95.1% reduction from week 10 to week 15. The $CG_{25}$ filter showed lower $BOD_5$ removal rates in weeks 2, 3 and 4, but performed better from week 5 forward to the end of the period.

In general, each filter seemed to have a different removal efficiency at the start, but all reached their maximum removal rates after week 6 in excess of 95%.

As the biomat on the surface of the filter media forms, the filtration rate reduces and forms an equilibrium with the incoming effluent and outgoing filtrate. It is unclear when the ultimate filtration performance of the sand columns will be achieved and how the filtration performance of CG will trend over several years' worth of testing.

*Table 2: TN removal*

| Source | FL | TN | |
|---|---|---|---|
| | | 23rd Oct | 30th Oct |
| Septic tank | | 36.1 | 51.5 |
| 2A sand filter | 50 | 14.4 **(60.1%)** | 22.3 **(56.7%)** |
| CG filter | 50 | 11 **(69.5%)** | 19.4 **(62.3%)** |
| CG filter | 25 | 11.2 **(69%)** | 20.3 **(60.6%)** |

(%) – Percent Reduction
TN is reported as mg/L
Filter loading (FL) reported as L/m$^2$/day

The filter influent and effluent were tested for TN on weeks 16th and 17th of the trial, all filters achieved removal rates within the 55% to 70% range as shown in Table 2. The two CG filters had similar removal rates and both were better than the sand filter. Additional nitrate reduction testing will provide robust nitrate removal efficiencies and is proposed to be completed in 2022/2023.

*Table 3: E.coli removal*

| Source | FL | E.coli | |
|---|---|---|---|
| | | 11th Nov (Hill Labs) | 25th Nov (Hill Labs) |
| Septic tank | | 16,000 | 160,000 |
| 2A sand filter | 50 | 2 **(log3.9)** | 2 **(log4.9)** |
| CG filter | 50 | 2 **(log3.9)** | 2 **(log4.9)** |
| CG filter | 25 | 2 **(log3.9)** | 2 **(log4.9)** |

(log) – Log Reduction
E.coli are reported as MPN

The testing of both effluent and influent for E.coli needs to be conducted within 24 hours of sampling, however, it impractical due to small filtrate volumes during testing [16]. Therefore, the information demonstrated in Table 3 is indicative only and should not be relied on for any purpose.

Table 4 shows the laboratory results of filter influent and effluent for the monitored parameters; it also shows the respective removal rate for each filter.

*Table 4: Average waste strength and removal rates for filter influent and effluent*

| Source | Filter loading | TSS | $BOD_5$ | TN | pH | Temp. |
|---|---|---|---|---|---|---|
| Septic tank | | 56.1 | 107 | 43.8 | 7.4 | 19.8 |
| 2A sand filter | 50 | 2.2 **(96.5%)** | 5.6 **(94.7%)** | 18.4 **(58%)** | 6.9 | 20.2 |
| CG filter | 50 | 3.6 **(94.6%)** | 5.5 **(94.5%)** | 15.2 **(65.3%)** | 7.2 | 20.3 |
| CG filter | 25 | 5 **(92%)** | 8.9 **(91.3%)** | 15.8 **(63.9%)** | 7.5 | 20.4 |

(%) – Percent Reduction

TSS and $BOD_5$ are reported as mg/L    Filter loading reported as L/m$^2$/day

Temp reported as °C

## THE PERFORMANCE OF EACH FILTER MEDIA

Unlike raw CG media with a high concentration of contaminants when sourced, 2A sand was reasonably clean and free of fines or floatable fibres when sourced. The 2A sand filter, therefore, worked well from the start, with an average effluent concentration for TSS, $BOD_5$ and TN of 3.6 mg/L, 5.5 mg/L and 15.2 mg/L, which correlates quite well with the typical concentration of septic tank with sand filter as shown in Table 1. In addition, the average pH and temperature were 6.9 and 20.2, which are also within the normal range for sand filter effluent.

Recycled glass consists of a mix of clean and dirty glass vessels, jars and bottles. When dirty or partially full glass bottles such as beer, wine and medicinal bottles are crushed, the residual fluid slowly evaporates leaving a high concentration film behind. Unlike the 2A sand production method, CG is not washed, resulting in variable high concentration and negative removal rates for all waste strength parameters in the first week. Through continued effluent loading, the second week of the trial measured contaminate washed out, and the resultant performance trended to match the 2A sand performance.

The $CG_{50}$ filter's removal efficiency was 94.6% for TSS reduction and 94.5% for $BOD_5$ reduction, respectively, which is similar to the 95% removal rate of the 2A sand filter.

The $CG_{25}$ filter averaged 5 mg/L in TSS and 8.9 mg/L in $BOD_5$, equating 89.1% and 89.6%, respectively. The establishment of the biofilm was at a reduced rate due to the reduced loading rate, however once established, the $CG_{25}$ achieved similar removal rates to the sand filter and the $CG_{50}$ filter after two months.

Nevertheless, it was an interesting phenomenon as it shows the effect of hydraulic loading on the biomat establishment and performance of the filter.

Overall, the performance of both CG filters aligns with the literature review. The current information available on the performance of CG as a filter media shows that it could achieve a 91% reduction in TSS and 96% reduction in $BOD_5$, and results from this trial show that CG averaged 94.6% for TSS reduction and 94.5% for $BOD_5$ reduction. CG from this trial achieved a substantial 65.9% of TN removal, which is far more effective than the literature review. However, industry professionals have confirmed that a 60% TN reduction could occur under optimum conditions, therefore the 65.9% reduction of TN is acceptable.

Refer to Table 5 for a detailed breakdown.

*Table 5: Removal rates comparison between current literature and this project*

| Treatment system | Typical concentration | | | |
|---|---|---|---|---|
| | % | | | log |
| | TSS | $BOD_5$ | TN | FC |
| Septic tank with CG filter [14] | 91 | 96 | 29 | 3 |
| **Septic tank with CG filter (this trial)** | **94.6** | **94.5** | **65.9** | **NI** |

# $CO_2$ AND COST ANALYSIS

## $CO_2$ EMISSIONS FROM CRUSHED GLASS OR 2A SAND PRODUCTION

The main contributing factor to $CO_2$ emissions comes from fuel consumption of machinery and transportation. The $CO_2$ emissions were calculated by multiplying the total fuel consumption by 2.62 kg, which is the typical $CO_2$ produced by burning a litre of diesel. Emissions related to the installation of the sand trench and finishing of the discharge field are assumed equal due to the only change being the media.

Figure 7 displays the two production processes for 2A sand and CG from recycled glass.

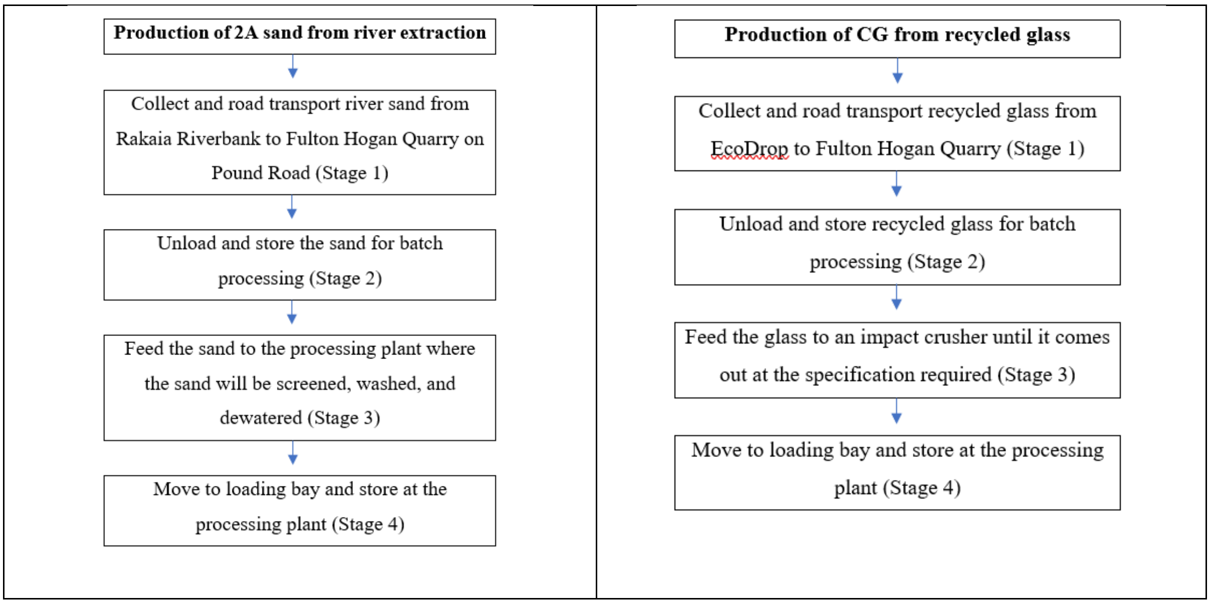


*Figure 7: Process flow for 2A sand and CG production (Source: Adapted from Fulton Hogan)*

The case study shows that while it only takes 37.50 litres of diesel to produce 20 tons of CG, it takes up to 115 litres of diesel to produce the same amount of 2A sand, which is an equivalent of 98 kg of $CO_2$ and 300 kg of $CO_2$ respectively [17]. The reason for the significant difference in $CO_2$ is due to the longer distance of travelling to collect raw sand from the Rakaia River. Recycled glass is typically collected from the curbside and processed nearby, therefore consuming less fuel overall.

The washing of the 2A sand was not included, as it is recommended that all CG undergoes the same process to prevent high concentration effluent in the first month of discharge to ground.

## COST ANALYSIS

The case study involved comparing the difference in media cost for the two media. The cost of the media was calculated by multiplying the cost per ton by the volume of 2A sand or CG needed to fill in a discharge control trench serving a three-bedroom home and a six-bedroom home. Using CG as a filter medium for a discharge control trench is more economical than 2A sand. By changing the filter material from 2A sand to CG, the contractor could potentially save as much as $500 for a three-bedroom and $1000 for a six-bedroom house. Refer to Table 6 for a complete breakdown.

*Table 6: Cost comparison for two scenarios (Source: Adapted from Fulton Hogan)*

| Trench media | Price ($/m$^3$) | Volume (m$^3$) | Cost ($/system) |
|---|---|---|---|
| 3-bedroom dwelling | | | |
| 2A sand | 87.11 | 10.8 | 940.79 |
| CG (2A) | 39.91 | 10.8 | 431.03 |
| 6-bedroom dwelling | | | |
| 2A sand | 87.11 | 19.4 | 1689.93 |
| CG (2A) | 39.91 | 19.4 | 774.25 |

# CONCLUSIONS

Based on data from the test trial and comparison with the baseline, it is now proven that CG could be a suitable substitute for 2A sand with loading rates up to 50mm/day. Overall, with the same hydraulic loading, CG performed similarly to 2A sand in terms of TSS, $BOD_5$ reduction. CG achieved a higher TN reduction than 2A sand. Between the two CG filters, the hydraulic loading does seem to have an effect on the removal rate of the filter at the start, but after eight weeks, both filters achieved similar removal rates in all tested parameters.

CG also contains pulverised labels and price tags which can decompose within the sand column or could be considered as microplastics, it is therefore recommended that manufacturers ensure clean glass without labels are used when crushing.

The price of CG is currently half of 2A sand, yet it produces significantly less $CO_2$ emissions than 2A sand, CG when used as filter media for a 3-bedroom dwelling could save up to $500 and reduce 200 kg of $CO_2$ released to the environment. Using crushed glass as a filter medium could lower the material cost for a trench filter and potentially create a viable market for the abundant recycled glass stockpile in New Zealand and remote locations such as the Chatham Islands where 2A sand is not available.

## ACKNOWLEDGEMENTS

ARA Institute of Technology for hosting the test rig in the Engineering Laboratory.

Andrew Dakers for providing crushed glass test results and technical guidance.

Fulton and Hogan for the samples and sourcing information.

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