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Performance Evaluation of Pumice as Green Wall Medium For Grey Water Recycling

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Abstract— The exploding urban population growth creates unprecedented challenges, among which provision for water and sanitation has been the most pressing and challenging. An attempt to address the issue of lack of access to freshwater resources for sustainable management of natural resources is greywater recycling using engineered vertical walls with efficient and economical green media. Greywater is a type of in-building wastewater which is nowadays recognized as a substantial alternative source of water after providing them with suitable treatment and disinfection, saving 30-50% of potable water yearly. Green walls are vertical vegetation system that offers various benefits compared to other conventional water treating technologies such as less land footprint, air quality control, improvement in indoor thermal comfort, and reduction in energy demands for heating and cooling. Despite this fact, only few studies about the application of natural media over the conventional sand medium have been conducted. Pumice is a porous adsorbent which can provide good drainage, aeration, nutrient-water retention capacity along with favorable surface conditions for bacterial growth that promotes biofilm formation. The study involved a comparison between the media pumice and sand using column study on their hydraulic properties, functional parameters, and efficiency in the removal of pollutants. Pumice was found to be a better medium than sand with impressive hydraulic properties, higher COD removal potential, turbidity removal at an efficiency of 56% but conductivity didn't show much variance. The study suggests more comparison tests with different proportions of media tested under different discharge rates which might prove to be a more cost-effective option for vertical green walls. The test results can be used for further studies for choosing the most effective media combinations for greywater recycling.

Index Terms—Filter-media Greywater Green-walls Green-media Pumice Reuse Water-recycling

1 Introduction

With the rapid growth and densification of our cities, there is an emerging need for on-site greywater treatment and reuse technology which can be built vertically, reducing the areal footprint [25]. Adequate treatment of greywater before reuse is important to reduce the risks of pathogen transmission and to improve the efficacy of subsequent disinfection [28]. Green walls that passively treat varying sources of polluted water are currently being considered to be one of the most environmentally friendly and low maintenance solutions for water recycling [26]. In addition to that, green walls have significant potential as a sound insulation tool for buildings [31]. These vegetated walls can use blank spaces of building walls and facades in addition to providing the visual aspect, undertake the function of wastewater treatment technology at the same time, eliminating their irrigation requirements [24].

Also, if the acceptable quality of treated water is achieved, it could be collected at the bottom of the green wall and reused for toilet flushing and irrigation, thereby transforming them into water producers [25]. In the study by Masi et.al,[14], the potential of green walls has been explored as a viable greywater treatment system that can greatly minimize the treatment footprint and provide a series of benefits in the urban landscape such as greening, carbon dioxide trapping, oxygen production, microclimate effects, house insulation, etc.(refer fig. 1).Fig. 1(b) shows the schematic diagram of a typical grey water treatment unit[14].

(a) (b)

Figure 1: a) Pilot green wall installed at MJP head office, Pune b) sketch of the treatment unit [14].

The major objective of the study is to characterize the material properties of media for the vertical green walls. The role of each element in the green wall is assessed and optimized to understand its impact on the life cycle of plants and media. The media must be efficient to treat greywater and capture the pollutants [11]. The study investigates the performance of media pumice and sand to treat and reuse greywater. The tiny pores of pumice can act as microscopic reservoirs to capture and store nutrients and cyanobacterial impurities [29]. Sand as a filtering medium can remove particles by absorption or physical encapsulation [9]. Characteristics of the media are analyzed and column studies are conducted on the media. The greywater is prepared in the laboratory using a standard proportion of chemicals. Influent and effluent characteristics of the column study are determined using various physical and chemical tests. The removal efficiency of the pumice medium is determined and the performance curve plotted to compare it with that of sand.

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2. Materials and methods.

2.1 Selection of green wall media

An extensive literature review was conducted to identify potentially suitable media for application in green walls. Materials were selected based on their horticulture applications, density, optimum moisture and nutrient retention, hydraulic conductivity, porosity, the capacity to support plant growth, sustainability, and local availability. Pumice and sand (refer fig. 2) were the two selected media for the experiments. Pumice is well known for its capture and retention of cyano-bacterial impurities with good COD removal and sand was selected for the comparative study as it is the most common and conventional medium used for gardening. The media were tested for various physical characters and hydraulic performance.

(a) (b)

Figure 2: The two different filter media a) sand and b) pumice

2.2 Fabrication of column

The experimental set up consisted of four acrylic glass columns, each held tightly by four rings fitted into a rigid five-legged cast iron stand with provisions for individual water discharge from the above PVC water tanks. The acrylic glass columns were of 50 mm diameter and 200mm height, out of which 150mm contains filled medium and 50mm freeboard for extended detention of water. Plastic meshes were placed on top of the medium layer to keep it in place and prevent it from floating. The bottom of the column had an outlet valve to collect the effluents at intervals. The overhead water tank was made of PVC with 50mm diameter and 100mm height which allows three different discharge rates for simulating the peak, low and normal flow of greywater generated in a real-life scenario.

Figure 3: Elevation view of the experimental setup with overhead water tanks.

2.3 Greywater source and characteristics

Greywater was prepared in a lab synthetically because undesirable health and environmental problems can be caused if real greywater is not used properly[22]. The health risks are due to the presence of pathogenic microorganisms and environmental impacts are mainly from the presence of nutrients (sodium, potassium, nitrogen) surfactants, pH, and micro-pollutants. It can also undergo degradation with time. Synthetic greywater was thus prepared following the standard composition chart to supply the large volume required for this experiment as well as to operate under controlled conditions. Target pollutant concentrations were selected to mimic the composition of greywater generated by typical household showers and hand basins. Chemical tests such as pH, Turbidity, COD, Conductivity, Total suspended solids, and Total dissolved solids were carried out according to standards (APHA-American Public Health Association), in the synthesized greywater sample.

2.4 Dosing regime

The performance of the media under maximum and minimum inlet discharges of grey water to be treated should be thus studied to know the efficiency of real-life implications as they serve as the growing recycling media on vertical green walls. The discharge rates of the two overhead water tanks were calibrated first using normal water and later using synthesized greywater to find the dependency of rate of greywater loading on two media and the removal performance during each discharge rate. The outlet valve of the overhead PVC water tanks could be rotated by three different angles (refer fig. 4), thus allowing three different discharge rates slow, normal, and high. The water flowing per second through each tank for different angular openings were collected and tabulated. The result of the study is tabulated as shown in table 1.

Table 1: Dosing rates

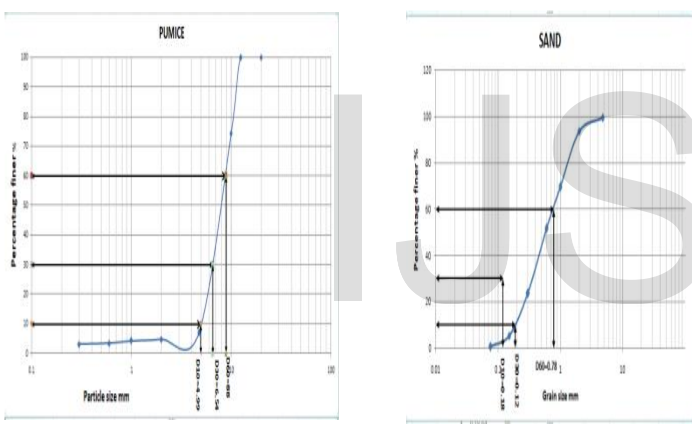
Water	Tank	30º	60º	90º
Normal water	No. 1	5.1 ml/s	14 ml/s	14 ml/s
	No. 2	2.16ml/s	11.6 ml/s	14.6 ml/s
Synthesized greywater	No. 1	4.6 ml/s	14.2 ml/s	21.43 ml/s
	No. 2	4.03 ml/s	16.8 ml/s	19.55 ml/s

Figure 4: The opening of the outlet valve.

3 Results and discussion

3.1 Filter media properties

Dry sieve analysis was carried out to find the particle size distribution of each medium according to the IS: 2720 (Part 4)-1985 standard procedures. The particle size distribution curve was plotted (refer fig. 5). The particle density and other physical parameters of the media were calculated and tabulated. The medium with the highest effective size was found to be pumice and the medium with high homogeneity or coefficient of uniformity was sand.The specific gravity of sand was found out to be 2.603 g/cc in its well-graded form. The specific gravity of pumice couldn't be found as it was seen floating in water inside the pycnometer indicating it is lighter than water showing it has a specific gravity of less than one. The material must be having larger air voids which will reduce the water holding capacity of the medium as they will be more permeable. Meanwhile, the sand having a greater value of specific gravity would allow the greywater to stay in the media for more time and facilitates purification. They also have less void volume which reduces permeability. The results of the different physical tests are tabulated in table 2.



(a) (b)

Figure 5: Particle size distribution curve of a) pumice and b) sand.

Table 2: Physical characteristics of media.

Sl. No.	PUMICE	SAND
D_{10} (mm)	4.99	0.18
D_{30} (mm)	6.54	0.12
D_{60} (mm)	8.88	0.78
C_u	1.77	4.33
C_c	0.96	0.10
Particle density (g/cc)	<1	2.603
Density (g/cc)	0.390	1.79

3.2 Hydraulic performance

The test results of the infiltration rates of media according to the constant head permeability test, after being packed into columns to acquire the above density is tabulated in Table 3. Pumice showed to be the faster media than sand, with a permeability coefficient of 9.525×10-3 m/s for a discharge rate of 14.66×10-6m3/s with density 0.390 g/cc, while sand had a permeability coefficient of 6.935×10-3 m/s for a discharge rate of 14.03×10-6m3/s with density 1.79 g/cc. The infiltration rate of the slow media showed a slight decline under high discharge rates preferably due to sediment build-up or biological clogging. The rapid increase in the permeability rate of faster media under high discharge rates from 6.175×10-3 to 9.525×10-3 might be due to media flushing or formation of new flow paths.

Table 3: The permeability test results of media.

Media	Discharge rate at which test was conducted(m^3/s)	The average value of K (10^{-3} m/s)
Pumice	2.16×10^{-6}	1.742
	11.66×10^{-6}	6.175
	14.66×10^{-6}	9.525
Sand	5.10×10^{-6}	4.96
	14.03×10^{-6}	6.935
	14.72×10^{-6}	6.27

3.2 Preparation of greywater and chemical characteristics

The preparation of synthetic greywater consisted of 100 mg/l of kaolin which replicated the suspended solids, 50 mg/l of sodium dodecyl sulfate to imitate the anionic surfactants, 200 mg/l of glycerol to duplicate the moisturizing agent in cosmetics and other solvents, 70 mg/l of sodium bicarbonate to represent the pH buffer and 50 mg/l of sodium sulfate to depict the viscosity control agents. The concentration of these products is shown in table 4 and a picture of the prepared greywater is depicted in fig. 6.

Figure 6: Synthesized greywater

TABLE 4: THE CONCENTRATION OF CHEMICALS IN SYNTHETIC GREYWATER.

Product	**Concentration (mg/l)**
Kaolin	100
Sodium dodecyl Sulfate	50
Glycerol	200
Sodium bicarbonate	70
Sodium Sulfate	50

The chemical characters of the synthesized greywater are tabulated below (refer to table 5). The prepared greywater was found to be acidic with high COD content. The amount of solids present was also quite high but the presence of conductive solids was less. The turbidity of the synthesized greywater was quite normal.

TABLE 5: CHEMICAL TESTS RESULTS OF SYNTHESIZED GREYWATER

Sl.no	Test	Value
1	pH	6.9
2	Turbidity	42 NTU
3	Conductivity	345 mS/ cm
4	COD	1675.629 mg/l
5	Total solids	1700 mg/l
6	Volatile solids	1550 mg/l

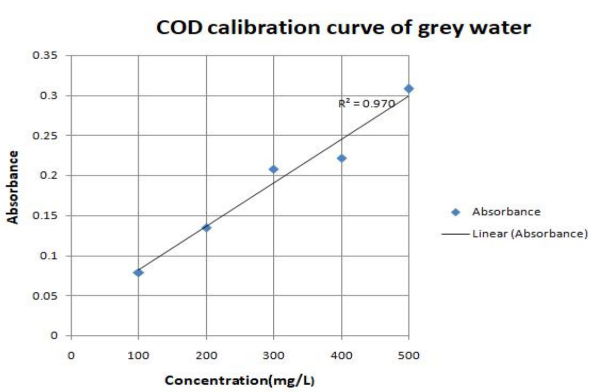


Figure 7: COD Calibration curve of greywater

3.4 Pollutant removal performance

Greywater was planned to discharge at the earlier calibrated three discharge rates for conducting a one-dimensional column study and retain them for the mentioned time intervals. But the high discharge rates through the valves and the small size of the column resulted in the overflowing of the columns even before the end of time intervals. So the work was restricted to allow water flow through media at no specific rate to ensure no overflowing, then the water was retained in the media for the specified time intervals and later collected through the outlet valve for testing. Later performance curve (refer fig. 8) was plotted to find the optimum retention time of the media for the best pollutant removal efficiency.

3.4.1 Conductivity

The conductivity of greywater flowing through pumice decreases as time passes shown by the steeper slope in the performance curve (refer fig. 8). It shows that the conductivity of the greywater goes on reducing as the retention time increases. Higher the time greywater is in contact with the pumice medium, the lesser is the conductivity of the effluents. Sand has a highly uneven performance curve. It shows the lowest value at the end of the 1^{st} hour and highest at the end of the 2^{nd} hour. This indicates that the conductivity of the effluent is the minimum if it is retained on the medium for 1 hour and increases if retained for 2 hours but goes on mildly reducing after that. Thus it can be concluded that the performance of the lightweight medium pumice is more stable in the removal of conductive solids in greywater than conventional medium sand.

3.4.2 TDS

Solids concentration in greywater shows a steady decrease when pumice was used as the filter medium. But since freshwater has a TDS of about 392 mg/l [23] and pumice shows a high removal rate of total dissolved solids, the treated water cannot be used for irrigation purposes, but as time passes TDS might develop due to natural forces. Meanwhile, the concentration of inorganic salts is shown to be sufficient for plant growth after passing through the sand medium. The amount of TDS has shown a heavy increase after the second hour in the sand medium but further went to show a steady decrease towards the 6^{th} hour. The prescribed amount of TDS in water for irrigation purposes could be achieved after retaining grey water on the sand medium for 3-4 hours. Thus pumice was found to be unfit for retaining sufficient amount of inorganic salts essential of plant growth in the medium.

3.4.3 Turbidity

Turbidity has uneven variations with time in the pumice medium with the highest turbidity noted at the first hour which significantly reduced at the end of the 6^{th} hour. Greywater collected after the 1^{st} hour from pumice is highly turbid as it shows the highest peak. The lowest value is at the 6^{th} hour of retention which indicates the decrease in turbidity as time passes. The turbidity of greywater passed through sand has its highest peak in the performance curve at the end of 2hrs of retention which keeps on reducing later till the end of the 6^{th} hour. The comparison of results shows that the turbidity of greywater after retaining on two medium for one hour was found out to be the same but sand has shown a high rate of removal as time passes than the pumice.

3.4.4 pH

From the column study in pumice, it is visible that the acidity of the effluent coming through the medium gets reduced as the time retained on the medium increases. The curve has shown the lowest value of pH for pumice, at the first hour which says that the acidity of the effluent greywater increases when the water is retained in the medium for 1 hr. The sand was used as a reference medium whose effluents showed lesser acidity when compared to pumice. Greywater passed through sand is found to be less basic at the end of 1st hour and more basic at the end of the 5th hour. However, pH has uneven variations as time passes through both the media. Pumice showed high retention of acidic salts in greywater in the medium for more time,making the effluent also acidic. The freshwater for irrigation should have a pH in the range 7 to 7.2 which could not be achieved through pumice medium but through the sand.

3.4.5 COD

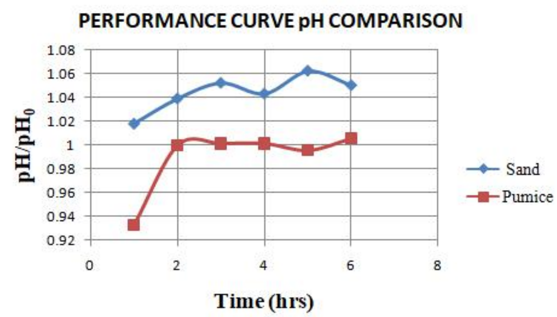
Generally, the COD value of the prepared greywater was very high than the real grey water and is found to be reduced when passed through the medium pumice. It shows the efficiency of pumice as a good filtering medium for chemical pollutants. When greywater was passed through pumice and performance curve plotted after column study, the lowest point in the graph was found at the end of the 3rd hour. This indicates that retaining the greywater in pumice medium for 3hrs could efficiently reduce COD. But the highest peak or value of COD in effluents was found at the end of the 5th hour. So as time increases the COD removal efficiency of the medium reduces.

TABLE 6: COLUMN STUDY ON PUMICE AND THE EFFLUENT CHEMICAL PARAMETERS

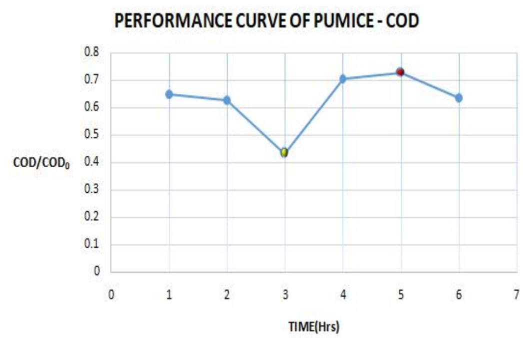
Time interval (hrs)	Conductivity (µS/cm)	TDS (mg/l)	COD (mg/l)	Turbidity (NTU)	pH
1	407	241	1086.36	17	6.44
2	383	184	1049.47	9.5	6.90
3	348	180	726.73	7.7	6.91
4	301	167	1183.614	12	6.91
5	276	149	1218.477	11	6.87
6	255	145	1068.01	6.5	6.94

TABLE 7: COLUMN STUDY ON THE SAND AND THE EFFLUENT CHEMICAL PARAMETERS

Time interval (hrs)	Conductivity (µS/cm)	TDS (mg/l)	Turbidity (NTU)	pH
1	5.45	2.72	16	7.03
2	846	425	23	7.17
3	787	388	15	7.26
4	511	258	7.4	7.20
5	400	227	4.5	7.33
6	416	212	4.3	7.25



(a)



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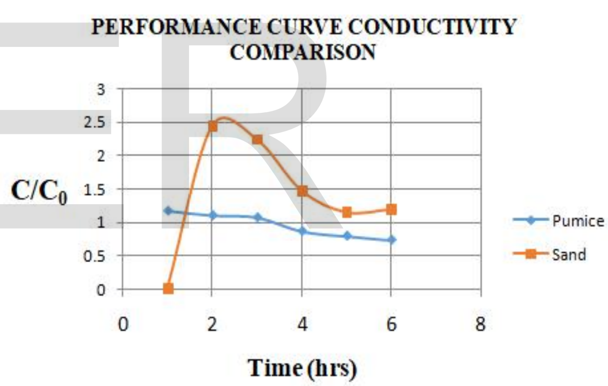

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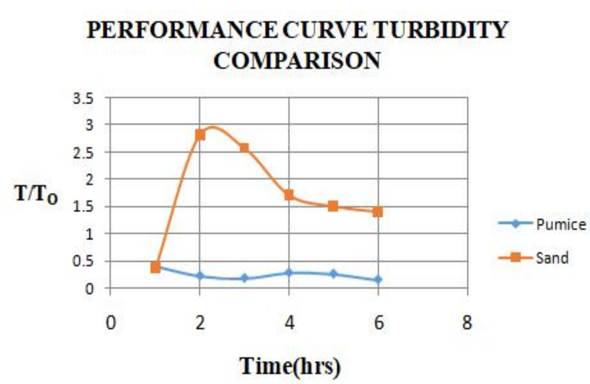

(d)

Figure 8: Performance curves of pumice and sand in pollutant removal performance.

4. Conclusion

One of the rising concern in a developing country like India is the scarcity of water for even the basic necessity of human beings. Greywater recycling using vertical green walls has proven to be very effective in the filtration and removal of contaminants from water. It has gained considerable interest in the greywater treatment industry because of its low power input, environmentally friendly, economical, compact process, and lower land footprint. This system serves different purposes like the treatment of greywater, reduces the consumption of natural water resources for gardening and irrigation, and provides better noise attenuation. The chosen medium pumice is locally available and cheap which makes its scope more broad and adaptable in vertical green walls. Thus the application of the project can be focused on even small residential households ranging to big shopping malls, educational institutions, and government offices. The following conclusions were made from the results obtained:

- The synthesized greywater used to do the chemical tests was found to be acidic with high COD content than real greywater. The amount of solids present was also quite high but the presence of conductive solids was less. The turbidity was quite normal.
- It was also found that the conductivity of effluent greywater did not vary much from the original value while passing through both the media. So the medium pumice showed to be unsuitable if the conductivity of the influent greywater has to be treated.
- Pumice has shown a higher COD removal efficiency in the 3rd hour. Pumice reduced COD from 1675.629 mg/l to 726.73 mg/l at the end of the optimum retention time of 3 hours. So, it would be ideal to retain greywater for 3 hours in pumice to get effluent water with low COD for irrigation purposes.
- pH did not vary much from the original value of greywater both in pumice and sand. But as long as the water was retained on pumice, pH was found increasing and at the end of 6 hours, a pH range (7-9) close to a freshwater source could be achieved.
- At a period of 3 hours, pumice had a greater turbidity removal than sand showing an efficiency of 56%. Pumice was successful in bringing down turbidity from 42 NTU to 7.7 NTU at the end of optimum retention time of 3 hours, while sand took 4 hours to achieve the same removal efficiency.
- So pumice also being the fastest medium, has proven to be better than the conventional medium sand, in the removal of turbidity & COD. Pumice has the largest effective size and well-graded coefficient of uniformity, so half the amount of the same medium now could be used to fill three pots which were earlier used for filling using sand, which strengthens the justification of it being an economical medium. And also with a specific gravity less than one, the weight of the filled pots would be also less than the normal heavy pots.
- To improve the test results, further tests can be carried out by varying the surface area of the medium by powdering it and carrying out a column study again with real greywater. After choosing the optimum media size and combinations, it can be taken in pots at the desired ratio for growing plants suitable for the climatic conditions[14]. The test results can be used for further studies and the most effective media combinations for greywater recycling can be chosen wisely.

This study inspires a new outlook in water recycling strategies which coins two pressing concerns which are wastewater management and freshwater conservation. Incorporating vertical walls in residential buildings and using recycled greywater for irrigation, toilet flushing, etc., can not only save a huge amount of water daily but also reduce the pollution load of wastewater on natural water bodies.

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