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RECYCLED POROUS CONCRETE EFFECTIVENESS FOR FILTRATION MATERIAL ON WASTEWATER TREATMENT

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ABSTRACT: The use of concrete waste from the demolition of buildings is one of the conservation efforts to reduce its environmental impact. In this study, concrete waste was destroyed by the size of coarse aggregates, then made into porous concrete. Porous concrete from recycled coarse aggregate was used as filtration media to reduce the pollutants in wastewater to satisfy the water quality standards. For this purpose, wastewater from the communal wastewater treatment plant was filtrated through two layers of porous concrete made of recycled coarse aggregate with several different sizes, and the water quality output of the system was measured according to water quality parameter standard. The objective of this study is to examine the effectiveness of the aggregate sizes of normal coarse aggregate compared to recycled coarse aggregate as filtration media. From the result of the water treatment filtration model, it was found that the size of coarse aggregate in the porous concrete mix has a significant effect for reducing the water pollutants, as biological oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solids (TSS). As a result of this study, porous concrete made from recycled coarse aggregate shows better performance on filtrating the water pollutants.

Keywords: Wastewater treatment, Porous concrete, Recycled coarse aggregate, Water quality.

1. INTRODUCTION

Domestic wastewater comes from residential businesses and activities, restaurants, offices, commerce, apartments, and dormitories. It is generally called grey water and black water, which is very influential in decreasing water quality. Some parameters such as the total coliform content, BOD (Biological Oxygen Demand), COD (Chemical Oxygen Demand), Ammonia, pH, temperature, and TSS (Total Suspended Solid) are very dominant and each is affected in different ways [1, 2, 3].

Porous concrete is concrete which is permeable or can absorb water. By relying on the absorption and pore power of the porous concrete, it is expected to be a filtration medium to reduce some contaminants in the wastewater. Porous concrete is composed of water, cement and coarse aggregate. The coarse aggregate used in this study is recycled aggregate which is derived from concrete that has been unused and reused. The use of concrete waste from the demolition of buildings is one of the conservation efforts to reduce its environmental impact.

Porous concrete is also called previous concrete which generally only uses coarse aggregates with a uniform gradation size so that it has a larger size pore, which allows drainage to drain water through the pore. Porous concrete has several advantages, including a high void content of about 30%, so it is potential to reduce runoff to the drainage system with a flow rate of 0.34 cm/second, making it effective for pavement, footpaths, and sidewalks [4], beside those it can be a constructive alternative with low environmental impact and protect water quality. Porous concrete also has a higher void ratio and permeability compared to conventional concrete, so that it can be used for the construction of wastewater treatment plants and as a construction material for sea walls [5]. Porous concrete can also be used for groundwater refilling [6]. Besides, as a detention system, porous concrete can remove stormwater pollutants from the runoff, which significantly decreases the concentrations of total suspended solids, nitrate, chemical oxygen demand, and increases the values of pH and sulfate [7].

Recycle aggregate is an aggregate derived from conventional concrete that is no longer used, and then destroyed to become an aggregate for a new concrete mix. Coarse aggregates used in this study were natural coarse aggregates (NCA) and recycled coarse aggregates (RCA).

A recent study on porous concrete shows that recycled coarse aggregate with high water absorption can replace up to 75% of low quality natural coarse aggregate (NCA) and increases its compressive and splitting tensile strength [8]. Therefore, a comparison between natural coarse aggregates (NCA) and recycled coarse aggregates (RCA) is essential.

The aggregate variations used in this study are aggregates with a diameter of 0.5-1 cm, 1-2 cm, and well-graded 0.5-2 cm for RCA and NCA. NCA comes from natural aggregate material, while RCA was taken from conventional concrete crushing with a compression strength of parent concrete f'c 22.5 MPa.

Water absorption in concrete is obtained from the ratio of the weight of pore absorbable water to dry concrete, which is expressed in percent, which serves to determine the amount of water content in the concrete. A void can be interpreted by the total percent of the pore number on the total volume. For the average, porous concrete has a pore percent value of 15-25% and the permeability is generally between 2 - 30 mm/sec [9]. The pore number is determined according to ASTM CI688.

Permeability is generally influenced by the aggregate size and proportion [9]. Permeability measurements are calculated based on ACI-522R. The falling head method is used for measuring permeability in concrete. This permeability measurement usually uses a cylindrical test object with a diameter of 100 mm and 200 mm height. The cylinder is placed in a PVC pipe. Testing is done after 28 days of curing [9]. Urban water needs include 25-35% for industry, 5-10% for public use, 10-20% for commercial, firefighting, and 30-50% for housing [10].

Wastewater released by disposal can be analyzed through the discharge of the needs of each resident. According to Tchobanoglous [10], the amount of wastewater produced ranges from 50-80% of the use of clean water. For the calculation of the amount of wastewater produced by the service area, 80% of the consumption of clean water is determined. The value of 80% versus 20% is the comparison between direct connections to urban public hydrants for medium economic communities, while the value of 30 L/person/day is the standard of clean water needs for urban public hydrants. The wastewater factor for drinking water is 0.5-0.8 [10].

Quality standards for domestic wastewater according to the Minister of Environment and Forestry of the Republic of Indonesia as a reference for this study can be seen in Table 1.

Table 1 Quality standards for domestic wastewater

Parameter	Units	Maximum level
pH	-	6 – 9
BOD	mg/L	30
COD	mg/L	100
Oil and Grease	mg/L	5
Ammonia	mg/L	30
Total Coliform	Amount/100 ml	3000
Discharge	L/person/day	100

The parameters of domestic wastewater are a measure of the wastewater content that can calibrate the wastewater. This parameter is used as a reference for domestic wastewater to achieve quality standards. Parameters for each type of waste vary. In domestic wastewater, the parameters used as reference quality standards are pH, BOD, COD, TSS, oil and grease, ammonia, total coliform, and discharge.

The purpose of this study is to examine the effectiveness of the aggregate sizes of normal coarse aggregate compared to recycled coarse aggregate, on filtrating the water pollutants to satisfy the water quality parameter standard.

2. METHODS

The research sets at a local integrated domestic wastewater treatment plant in Tlogomas, Malang, Indonesia, which covered domestic wastewater (gray water and black water) from 112 families with a total of 14 tanks. In this study, the concrete material uses natural concrete aggregates (NCA) and recycled concrete aggregates (RCA) with three variations, namely, 0.5-1 cm, 1-2 cm, and 0.5-2 cm.

The tested domestic wastewater treatment plant single model is 60x60x100 cm in size with two slab concrete dividers as filtration mediums, which is 60x60x5 cm each in size. The water used as a sample is domestic wastewater (gray water and black water) from a local wastewater treatment plant in the first tank (after the crushing tank). Inlet discharge is 2 L/min, with a calculation of deposits every 18 hours, calculation of water level every hour and samples were taken at the end of the three hours experiment.

Water quality of wastewater treatment plant in the original tanks and at the experiment tank model after filtered is tested at the time of each layer (BOD, COD, TSS, Ammonia, Oil and grease, Total Coliform) in addition to measuring pH and temperature, water level and height of sediments. Void ratio of porous concrete and concrete permeability are tested separately.

The output of water quality testing is the effectiveness of porous concrete as a filter for wastewater treatment where normal porous concrete aggregates become a comparative material for porous recycle aggregate concrete.

Comparison of the ratio of the proportion of weight in the manufacture of porous concrete, namely Cement: Gravel: Water is 1: 4: 0.3. The composition of NCA (Normal coarse aggregate) and RCA (Recycled coarse aggregate) aggregate sizes can be seen in Table 2.

From each variation, two slab test specimens were made for each trial session in the form of concrete plates measuring 60 cm wide, 60 cm long and 5 cm thick. Concrete samples will also be made specifically for the calculation of the void ratio and permeability of the nine existing variants.

Table 2 Aggregate size compotition in porous concrete

Aggregate		A (0.5 - 1 cm)	B (1 - 2 cm)	C (0.5 – 2 cm)
1	NCA	100% NCA 0.5-1	100% NCA 1-2	100% NCA 0.5-2
2	RCA	100% RCA 0.5-1	100% RCA 1- 2	100% RCA 0.5-2
3	NCA : RCA	50% RCA 50% NCA 0,5-1	50% RCA 50% NCA 1-2	50% NCA 50% RCA 0.5-2

3. RESULT AND DISCUSSION

This study is aimed at the efficiency value of the aggregate sizes of normal coarse aggregate compared to recycled coarse aggregate, on filtrating the water pollutants to satisfy the water quality parameter standard.

3.1 Void Ratio and Permeability

The pore number shows the number of pores in the concrete. The concrete pore number is in line with the amount of porosity in the concrete.

The void ratio test is carried out on fresh concrete. This test is carried out after the concrete is removed from the stirring [9]. Void ratio analysis can be calculated with Eq. (1) by using Eq. (2).

$$\textit{Void content (\%)}= \frac{T-D}{D} \times 100 \quad (1)$$

$$D = \frac{(M_c - M_m)}{V_m} \quad (2)$$

Where,
M_c = mass of measure filled with concrete
M_m = net mass of concrete
V_m = volume of measure
T = M_s/V_s (theoretical density)

The permeability analysis is used to see how much absorption by the porous concrete is displayed with the symbol k. Permeability measurements are calculated based on ACI-522R. Permeability of porous concrete is calculated using Eq. (3).

$$k = \frac{A_1 l}{A_2 t} \log \frac{h_2}{h_1} \quad (3)$$

Where,
k = water permeability
A_1 = cross-sectional area of specimen (150mm)
A_2 = cross-sectional area of the tube (150mm)
l = length of the specimen (150 mm)
t = time
h_1 = the initial water head (300mm)
h_2 = the final water head (1 mm)

The results of pore and permeability calculations are explained in Table 3. The relationship between pore number and permeability does not appear to be significant.

Table 3 Calculation Results of Void Ratio and Permeability

Coarse Aggregate Mix	Void Ratio %	Permeability (mm/s)
100%NCA 0.5-1	9.772	4.878
100%NCA 1-2	10.615	4.824
100%NCA 0.5 -2	8.720	9.248
50%NCA50%RCA 0.5 -1	8.587	7.317
50%NCA50%RCA 1-2	11.672	11.367
50%NCA50%RCA 0.5-2	5.940	7.332
100%RCA 0.5-1	4.865	6.264
100%RCA 1-2	5.186	8.865
100%RCA0.5-2	8.263	8.052

A comparison of the void ratio of the nine mix designs in this study can be seen in Fig. 1. The picture shows that the smaller the aggregate size, the smaller the void ratio value. It can also be interpreted that the smaller the aggregate size, the smaller the porosity, and the ability to store fluid is also getting smaller. This is because the pores between the aggregates are denser than the aggregates with larger sizes. 100% NCA 0.5-1 has a void ratio which is smaller than 100% NCA 1-2. From Table 2, it can be seen for the smallest void ratio value is a mixture of 100% RCA 0.5-1. The largest void ratio is found in a mixture of 50% RCA50% NCA. 1-2.

Void ratio values vary for each mixture. This is due to the aggregate's ability to absorb water in SSD (Saturated surface-dry) conditions are varies. Especially between a mixture of NCA, RCA, and 50% RCA50% NCA. In the NCA mixture, the porosity number is high, while the RCA mixture is low. From the result of the analysis, it can be seen that absorption of water in the RCA aggregate is smaller than the NCA. The reason is that the RCA used comes from concrete waste that had experienced SSD conditions previously, while

NCA used in the experiment is a fresh aggregate.

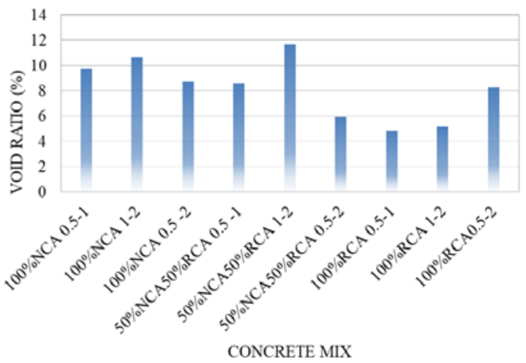

Fig. 1 Comparison for the porous concrete void ratio of each mix design

A comparison of the permeability of porous concrete in the experiment is explained in Fig. 2. From the figure, it can be seen that the highest permeability value is 50% RCA50% NCA 1-2 type mixture. This indicates that the highest absorption strength by 50% RCA50% NCA 1-2 porous concrete. The average mixture type with an aggregate size of 0.5-2 or evenly has a high absorption rate. For normal aggregates, the permeability is low, although the average void ratio value is high.

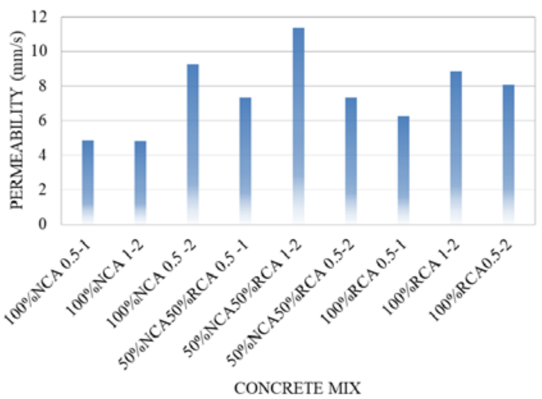

Fig. 2 Comparison for porous concrete permeability of each mix design

3.2 Analysis of Water Quality and Efficiency

The water quality tested in this study is under the quality standards of domestic wastewater namely temperature, pH, BOD, COD, TSS, Oil and grease, Ammonia and Total Coliform. To see the relationship between the efficiency of the reduction of the parameter and the void ratio and permeability, several graphs are made. In this graph, the value of oil and grease and total coliform is not included because there is no reduction value of these parameters in this study. Oil and grease and total coliform can only be decomposed and reduced using biological and chemical methods [11, 12, 13].

For comparison of the effect of aggregate sizes to the filtration ability, one of the results from the 50%NCA 50%RCA is shown for COD, BOD, and TSS, as shown in Fig. 3. It can be seen aggregate size of 0,5-1 cm and 0,5-2 cm show good numbers of efficiency compare to concrete with a bigger aggregate size of 1-2 cm, due to its bigger pores.

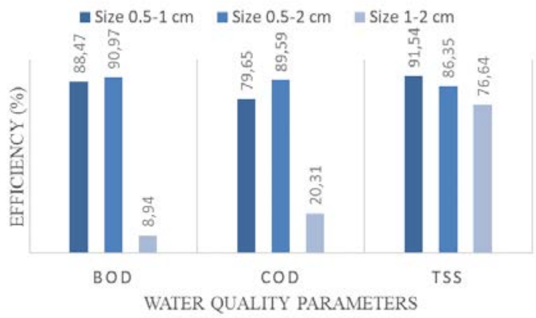

Fig. 3 Filtration result for different aggregate sizes with 50%NCA-50%RCA for COD, BOD and TSS parameters

A comparison of aggregate types with various sizes can be seen in Fig. 4, 5 and 6. In these figures, the effectiveness is compared for a different type of coarse aggregate in concrete mixture with the same sizes.

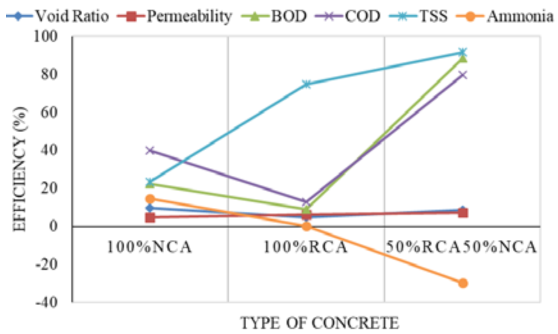

Fig. 4 Void ratio, permeability, and efficiency for every mixture with an aggregate size of 0.5-1 cm

In Fig. 4, for the aggregate size of 0.5-1 cm, the best percentage of efficiency is seen in the 50%RCA 50%NCA mixture type. But it has the lowest ammonia efficiency. This is because ammonia is not reduced only by physical methods, but by the addition of biological methods or by adding aeration to processing. This phenomenon also occurs in the concrete mix with an aggregate size of 1-2 cm and well-graded 0.5-2 cm.

While for 1-2 cm aggregate size, the highest value of TSS efficiency in 50%NCA 50%RCA mixture while BOD, COD is at 100% NCA. However, the highest ammonia reduction efficiency value is 100% RCA. The largest pore number is at 100% NCA. The biggest permeability is at 50% RCA 50% NCA.

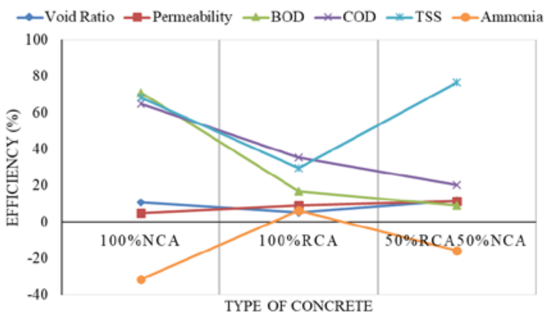

Fig. 5 Void ratio, permeability, and efficiency for every mixture with an aggregate size of 1-2 cm

For 0.5-2 cm aggregate size, it can be seen, that the efficiency value of TSS, COD, BOD has the highest value at 50%NCA 50%NCA. With a pore value lower than 100% NCA and higher than 100% RCA as well as its permeability value.

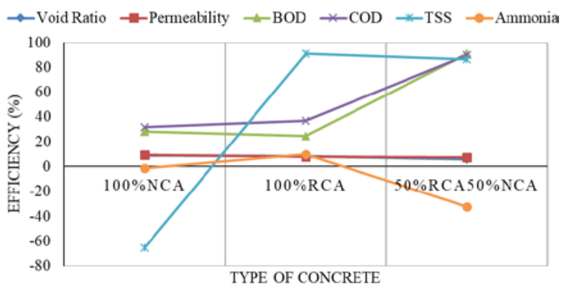

Fig. 6 Void ratio, permeability, and efficiency for every mixture with an aggregate size of 0.5-2 cm

A comparison of the types of aggregates in each type of concrete mixture is presented with graphs in Fig. 7, 8, and 9. In these figures, the effectiveness is compared for different sizes of coarse aggregate in concrete mixture with the same coarse aggregate type.

For the 100% RCA aggregate type, the highest efficiency values of TSS, BOD, COD, and Ammonia are in the mixture of 100% RCA size 0.5-2 cm. But the highest value of the pore is 1-2 cm. Whereas permeability is at 0.5-2 cm. In 100% NCA mixture 1-2 cm aggregate size has the highest efficiency for TSS, COD, BOD parameters. However, the lowest ammonia reduction efficiency is 1-2 cm. In 1-2 aggregate sizes with 100% NCA mixture types, the pore value is the largest compared to 0.5-1 and 0.5-2. 100% NCA 1-2 has the smallest permeability compared to 0.5-1 and 0.5-2 cm. For the 50% RCA50% NCA aggregate type, the greatest efficiency of TSS, BOD, and COD is 0.5-2 cm. But the biggest ammonia reduction efficiency value is 1-2 cm. Efficiency results of 0.5-1 and 0.5-2 in the 50% RCA50% NCA mixture are not much different.

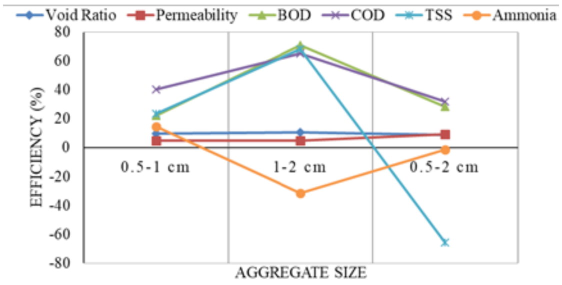

Fig. 7 Efficiency for water quality parameter at porous concrete with 100% of natural coarse aggregate (100% NCA)

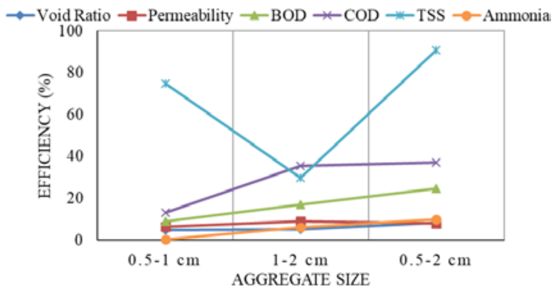

Fig. 8 Efficiency for water quality parameter at porous concrete with 100% of recycled coarse aggregate

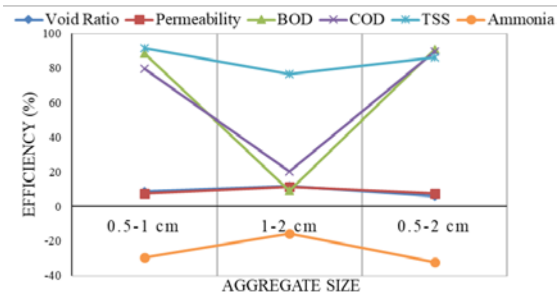

Fig. 9 Efficiency for water quality parameter at porous concrete with 50% RCA and 50% NCA

From the results of the analysis, the size of coarse aggregate in porous concrete mix significantly affected its filtration ability for reducing water pollutants. Generally, concrete mix with 0.5-2 cm aggregate sizes gives the best result, for the decrease of biological oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solids (TSS), due to its well-graded sizes. The porous concrete made from recycled coarse aggregate (RCA) shows better performance on filtrating the water pollutants compared to one made from natural coarse aggregate (NCA).

4. CONCLUSION

In conclusion, the size of coarse aggregate in porous concrete mix has a significant effect and highly efficient for reducing the water pollutants, as biological oxygen demand (BOD), chemical oxygen demand (COD) and total suspended solids (TSS), with 0.5-2 cm aggregate sizes for best result, due to its well-graded sizes. The porous concrete made from recycled coarse aggregate (RCA) shows better performance on filtrating the water pollutants compared to one made from natural coarse aggregate (NCA). Void ratio and permeability values cannot determine the efficiency of reducing pollutants by porous concrete. The outcome of this study can be used to develop an improved filtration system model of wastewater for residents with limited land in urban areas. To appropriately meet the water quality standard criteria, it is recommended in the future work to improve the filtration model by considering adding more layers, adding a wetland system, or combining with adding some additives. The cumulative sediments in the model should be well predicted as well.

5. REFERENCES

[1] Tiwari, S., Water Quality Parameters –A Review, International Journal of Engineering Science Invention Research & Development, Vol. I, Issue IX March 2015, pp.319-324.

[2] Mishra, R., Prajapati, R.K., Dwivedi, V.K., Mishra, A., Water Quality Assessment of Rani Lake of Rewa (M.P.), GERF Bulletin of Biosciences, 2011, 2 (2), pp. 11-17.

[3] Yimrattanabavorn, J., Rungrueang, O., Karuchit, S., Wirikitkhul, P., Assessing Urban Water Supply System in Northeastern Thailand: Water Quality and Authority Organization, International Journal of GEOMATE, Aug. 2018 Vol.15, Issue 48, pp.187-194.

[4] HarshavarthanaBalaji M., Amarnaath M.R., R.A.Kavin, S. Jayapradeep, “Design of Eco Friendly Previous Concrete”, International Journal of Civil Engineering and Technology (IJCIET), Vol. 6, Issue 2, February (2015), pp. 22-29.

[5] Pratap Singh H., Sharma K., Sakale R., Kumar K.S., “Enhancement the Strength of Pervious Concrete with Different Water Cement Ratio and Admixture”, International Journal of Engineering Research & Technology (IJERT), Vol. 5, Issue 01, January 2016, pp. 582-588.

[6] Vikram, Mahla R.P., “Experimental Study of Pervious Concrete Pavement”, International Journal for Research in Applied Science & Engineering Technology (IJRASET), Vol. 3, Issue 7, July 2015, pp. 40-48.

[7] Pilon, B.S., Tyner, J.S., Yoder, D.C., Buchanan, J.R., The Effect of Pervious Concrete on Water Quality Parameters: A Case Study, Water 2019, Vol. 11, no. 2, 263.

[8] Arifi, E., Cahya, E.N., Remayanti C., Effect of fly ash on the strength of porous concrete using recycled coarse aggregate to replace low-quality natural coarse aggregate, AIP Conference Proceedings 1887, 020055 (2017); American Institute of Physics, pp. 020055-1 - 020055-8.

[9] Joshi T., Dave U., Evaluation of Strength, Permeability and Void Ratio of Pervious Concrete With Changing W/C Ratio and Aggregate Size, International Journal of Civil Engineering and Technology (IJCIET), Vol. 7, Issue 4, July-August (2016), pp. 276-284.

[10] Tchobanoglous G., Burton F.L, Stensel H.D., Wastewater Engineering, Treatment and Reuse, 4th edition, McGraw- Hill, New York (2003).

[11] El-Gawad, H.S.A., Oil and Grease Removal from Industrial Wastewater Using New Utility Approach, Hindawi Publishing Corporation Advances in Environmental Chemistry, Volume 2014, Article ID 916878.

[12] Mueller, A.SS, et.al, Removal of Oil and Grease and Chemical Oxygen Demand from Oily Automotive Wastewater by Adsorption after Chemical De-emulsification, Practice Periodical of Hazardous, Toxic, and Radioactive Waste Management, Vol 7, no. 3, 2003, pp. 156–162.

[13] Scholz, M., Mineral and Biological Contamination of Soil and Crops Irrigated With Recycled Domestic Wastewater, Sustainable Water treatment, Elsevier, 2019, Pages 55-83.